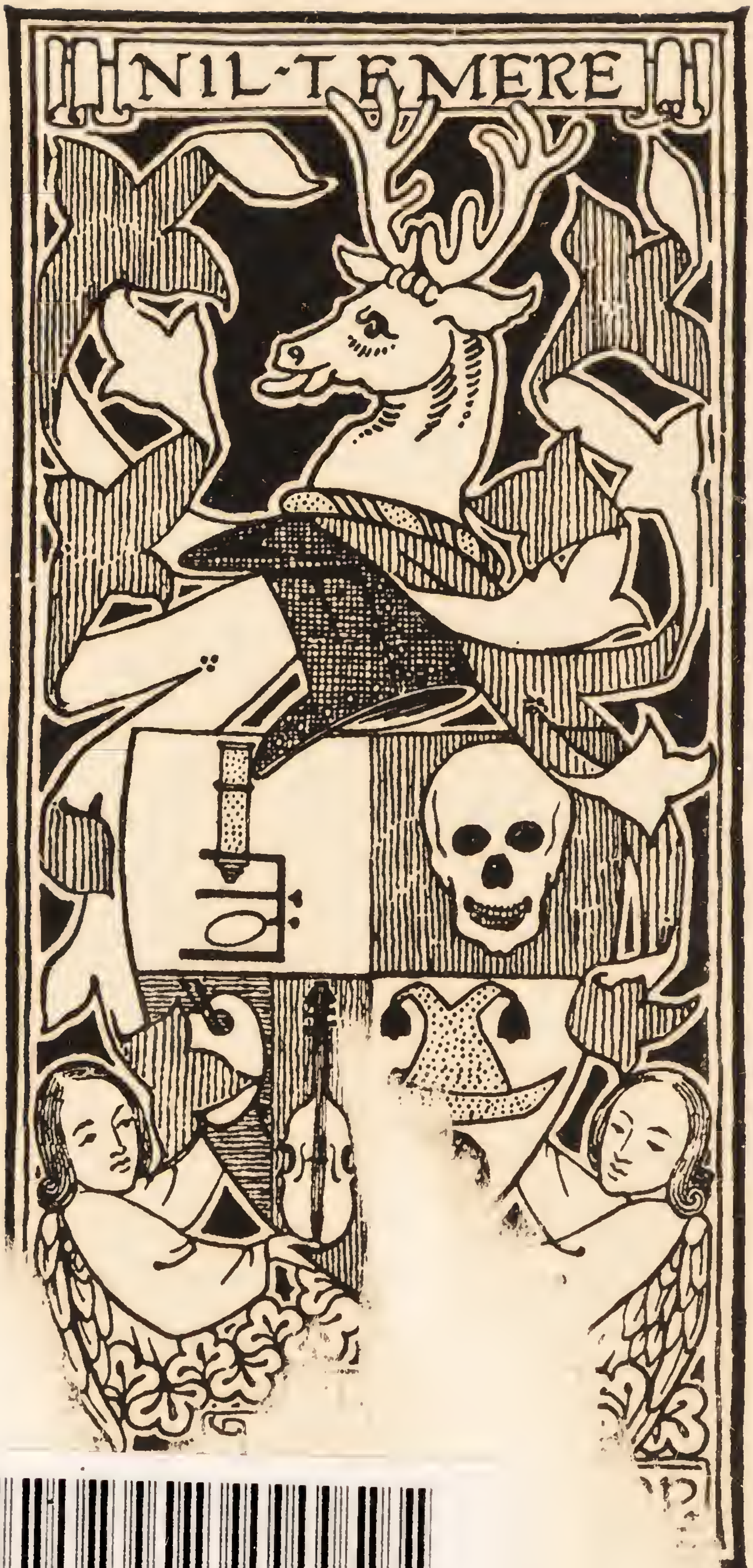

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The Physiology of Mind

An Interpretation Based on Biological, Morphological, Physical and Chemical Considerations

BY

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SECOND EDITION, RESET

Philadelphia and London

W. B. Saunders Company

1925

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Inscribed to the Memory
of
JOSEPH LEIDY
to whom especially we owe our
Knowledge of the Behavior
of the
Rhizopoda

PREFACE

As stated in the preface to the first edition, the object and scope of this book is to present the basic facts of those reactions of the organism to the environment which under given conditions manifest the qualities which we speak of as "mind." As far as possible elemental truths have been sought for in a consideration of the structure of the constituent substance of the organism, the living protoplasm. The physical peculiarities of the latter, its ceaseless chemical change, its simultaneous up-building and reduction, its reactions and its lack of reactions to the incident forces of the physical world, have, in turn, been called to the attention of the reader. Secondly, the behavior of simple unicellular forms of life has been compared with and in a measure correlated with the behavior of the individual cells of multicellular forms.

In due course, also, have been considered those peculiarities of structure of the living protoplasm which cause the arrest of certain,

a very limited number, of the incident forces of the environment. Protoplasm as a whole is "transparent" to and remains totally unaffected by an infinitude of forces active in the universe. In turn the writer has taken up the problems of the reception and transmission of the forms of energy which protoplasm is capable of receiving, the conversion of these incident forces into other forms, and the transmission and the release of energy by the protoplasm itself. Naturally, this discussion is preceded by a consideration of elementary responses to impacts, by a consideration of the differentiation in metazoa of special structures for the reception and transmission of impacts and for the resulting expression in motion; and this is followed by a consideration of the elaboration and differentiation of these phenomena in the more complex metazoa.

At first the responses of the organism are very general in character. Soon, however, they become limited and special, and later acquire the character of being fixed, stereotyped, and invariable. Later still, owing to an increase—an increase which finally becomes vast—in the number of the integers concerned in trans-

mission, and owing to the preservation in these integers of certain primitive and undifferentiated properties, the responses lose this quality of fixation. They become capable of variation and acquire the quality of being more and more adaptable and adjustable to the impacts received; the responses become more and more the exact or, rather, the increasingly approximate equivalents of the impacts.

In the present edition the nature of the transmission of impacts is next considered; this is shown to be indisputably electrical. The problem of consciousness and of the field of the latter are then taken up. Next our attention is occupied with the function of the thalamus, the synthesis of special sense impressions, the evolution and nature of speech, the function of the striatum and general cortical synthesis. In turn the conditions which influence the life and functions of the neurone, the play of the hormones, the problem of the instincts and tropisms, of pleasure and pain, are considered.

Attention is especially called to the remarkable physical facts definitely known in regard to the responses of the organism, facts which

possess a profound significance and which must greatly influence our conceptions both of the structure of protoplasm and of the limitations which this structure imposes. Here appears the great question: "What and how much does our structure permit us to know?" Finally the reactions of the organism are considered in the light of Einstein's conception of energy.

In the present edition the matter of the book has been divided into sections which the writer has endeavored to arrange into a logical and orderly sequence. Further, in an Addendum, the principles developed in the body of the thesis are applied to the pathological physiology of mind, and in an Appendix there is presented a brief, and the writer hopes, convincing consideration of Freudism.

Finally, a study of mind from the standpoint of physiology leads to the realization that the "physiology of mind" embraces what is ordinarily meant by "psychology." In any event psychology can only be regarded as a department of brain physiology. That there is an inherent objection to the term psychology has been pointed out in the text.

In conclusion the writer wishes to say for the lay reader into whose hands this book may fall, that, as far as practicable, the language employed has been as simple as the nature of the subject permits. Unfortunately, however, many technicalities are unavoidable, though, whenever possible, the meaning of these has been indicated in the text.

F. X. D.

1719 Walnut Street,
Philadelphia, Pa.
January, 1925.

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I

INTRODUCTION

To the writer it has seemed that all of the phenomena embraced by human experience, no matter what their character, must be approached from the standpoint of cold, unemotional, scientific observation and analysis. This necessitates as a preliminary an attitude of mind in which preconceived ideas, prejudices of whatsoever character, previous beliefs, and conceptions are set aside. In no field is this more important than in the study of the phenomena embraced under the term "mind." Long the subject of the discussions of metaphysicians and in later times of psychologists, the phenomena

of mind have been approached as though they were altogether peculiar in their character and being; as though a difference essential and intrinsic separated these phenomena by a wide and hopeless gap from all other phenomena of nature. Let us see whether such an attitude, such a preconceived notion, is justified.

When we turn our attention to some of the lower forms of life, for example, to the protozoa, and notably to the simple expression of life as witnessed in the amœba, we find that the organism reacts in an already complex manner to the environment; thus, when the pseudopod of an amœba comes in contact with a foreign body one of two things occurs: either the protoplasm of the pseudopod flows around the foreign body and thus takes the latter into the interior of its own substance, or the pseudopod is withdrawn. Here we have undoubtedly a "selective" action. If the foreign substance is capable of serving as food, it is appropriated; if not, it is rejected. Should the foreign body be made up both of material capable of serving as food and of material incapable of serving such a purpose, the two are separated; after a time the first disappears, apparently becomes a part

of the substance of the amœba; the second is ejected. No one, I believe, would be so venturesome as to interpret these phenomena as the volitional acts which they so closely resemble. Evidently they are merely the result of the physical (or physico-chemical)—or to state it in other words, of the electromagnetic—reactions of the protoplasm of the amœba with the material of the foreign body. Our increasing knowledge of the functions of the individual cells in the higher animals has taught us that not only have these cells the special functions pertaining to the tissues of which they are parts but also that they possess, in addition, like unicellular organisms, the primordial property of selecting, digesting, and assimilating their own food. It would appear that the cells of the various tissues possess each a special structure, a special metabolism; that is, that each cell contains special ferments by means of which it builds itself up, adds to its own substance out of the general material of the blood plasma. The cells thus have the power of "selecting" foreign materials, of fragmenting them, and of utilizing them for purposes of reconstruction or as sources of energy.

The purely physical character of these changes are, of course, beyond question. Fats are split into glycerine and fatty acids; carbohydrates are broken up; albumin is converted into peptones; the latter are split into amino-acids and these again into still simpler bodies. In turn, the cells give up into the blood-stream substances so far reduced that they are no longer sources of energy, can no longer play a rôle in the metabolism of the cell.

Not only have the cells of multicellular forms retained the power of selecting, appropriating, and discarding the various materials concerned in their metabolism, but such cells as are not fixed in the tissues, *e. g.*, the white corpuscles of the blood, have retained in addition the power of independent movement and of actually extending and retracting portions of their substance in every way comparable to the pseudopods of the amœba. Surely no one would ascribe the action of the individual cells of the multicellular animals to volition. Both the "selective" action and the power of reducing the material selected into components suitable for appropriation into its own substance are properties inherent in living protoplasm, and

which the tissue cell shares with the most primitive unicellular forms. No volitional, no so-called "psychic" act can be considered as entering into the phenomena. It seems almost superfluous to repeat that they are clearly the result of purely physical and chemical processes. They merely instance the action of colloidal substances upon each other and upon other substances; an action in which the ions of the contained crystalloids no doubt also play a part; in short, the problem is one of chemistry, of electromagnetic or equivalent reactions.

We have in the selection and appropriation of food by the cells of the tissues an instance of the retention by the individual cells of multicellular organisms of the primitive properties of the single cell of unicellular forms. When we turn our attention in multicellular forms to other properties which have likewise to do with the reaction of the organism to the environment, other equally interesting facts become apparent. Let us begin with sponges. According to Parker,[1] "Some sponges, such as the *Stylatella*, appear, when out of water, to be more or less

[1] G. H. Parker, Sc.D., "The Elementary Nervous System," Philadelphia and London, J. B. Lippincott Company, 1919, p. 26.

shrivelled or contracted and under other circumstances to be plump and well rounded out. The differences which, for reasons to be mentioned presently, are known not to be due to the simple physical loss of fluid, are apparently dependent upon a general contractility of the whole flesh of the sponge which, though slight, may nevertheless enable the sponge to change its form somewhat." Again, the dermal membrane of sponges which is a tissue which has not become differentiated into cells, but remains syncytic, has the property of closing the pores of the sponge apparently by flowing over and coalescing, thus forming "over the external end of the pore canal an extremely thin sheet, the pore membrane, near the middle of which the pore has disappeared."[1] The movement of the pore membrane "is hardly to be described as purely amœboid. It seems to represent a stage of differentiation between amœboid motion and simple muscle contraction which may well indicate the kind of contractility that the common flesh of the sponge possesses."[2] In addition, the pores may be closed in some sponges

[1] Parker, loc. cit., p. 34.
[2] Parker, loc. cit., p. 36.

not only by the formation of a pore membrane but also by the closure of the canal leading to the pore—the pore canal—itself. "This is probably due, according to Wilson, to a contraction of the epithelial lining in the pore canal acting after the fashion of a sphincter."[1] The cells of this epithelial lining "are in every way comparable to a primitive form of smooth muscle-fiber. Their superficial position places them in contact with the water passing through the canal, and, as they respond to differences in this water, they are without doubt capable of direct stimulation." To repeat, then, we have in the sponges not only a general contractility of the organism as a whole, together with an amœboid movement of the dermal membrane, but also a sphincter-like action in the canals due to specialized cells. The latter correspond to the smooth muscle cells of other metazoa. They have, of course, no nerve supply and are dependent for their stimulation to contraction on the physical contact with the changing water and its contained substances.

It is interesting to note that in the higher animals, muscle-fibers still exist which like these

[1] Parker, loc. cit., p. 35.

primitive muscle cells of sponges are capable of responding to direct physical stimulation independently of any nervous influence. This has been clearly demonstrated, for instance, by a number of observers to be the case in the iris. In fishes, amphibians, birds and mammals, and probably in the eyes of cephalopods, the sphincter of the pupil may be regarded as normally subject to direct stimulation by light, notwithstanding the fact that it is also under nervous control.[1] Similarly, the vertebrate heart muscle appears to be equally subject to direct physical stimulation. While the adult heart is abundantly supplied with nerves and, indeed, itself contains an abundance of nerve-cells, no such facts obtain, so far as is known, in regard to the developing heart of the embryo. Indeed, in the chick the heart appears in about twenty-three hours of incubation and begins to pulsate about six hours later, at a time when the neural crests and neuroblasts have not yet been differentiated. Hence, there is every reason to believe that in the beginning it is absolutely free from possible nervous influence and that its beat is purely myogenic.[2] Many similar in-

[1] Parker, loc. cit., pp. 50–53. [2] Parker, loc. cit., pp. 53–56.

stances of muscle activity independent of nervous influence might be cited. It is true apparently of the heart of the tunicate, of the muscle-fibers of the amnion of the chick, and of the circular and acontial fibers of sea-anemones.[1]

We have, then, as one of the primary facts of the reaction of the organism to the environment, a response in movement. This is expressed in the amœba in the movements of its pseudopods, and, in such multicellular forms as the sponges, in the movements of the syncytic dermal membrane, in the contraction of the cells about the canals, and in the movement of the body of the animal as a whole.

The next question that presents itself is as to the capacity of living protoplasm for the transmission of motion through its own substance. It is not my intention to take up at this point the reaction of protoplasm to light, to heat, to electricity, or to sound, but rather its reaction to those more grossly mechanical forces implied by the impact of foreign bodies. In the sense here employed mere contact implies such an impact. To begin, if transmission of a mechanical impact actually takes place, it would not be

[1] Parker, loc. cit., pp. 59–61.

surprising to find that this transmission is relatively slow. Proteins are extremely complex compounds. They are made up of many amino-acids; as many as seventeen. Emil Fischer, it may be recalled, succeeded in combining as many as nineteen amino-acids in the synthetic construction of an artificial protein. It is a legitimate inference from these and other facts that the structure of living protoplasm is that of an exceedingly complex colloid, the disperse and continuous phases of which must necessarily bear multiple and complicated relations of surface and interfacial tension and of electrical charge to each other. It would seem that considerable time relatively must necessarily elapse for the diffusion or transmission of a mechanical impact through such a mass.

That transmission or diffusion takes place from one part of a protozoan to another part as a result of impact or contact, is exceedingly probable. In the amœba the transmission appears to be more or less widely diffused, for not only a pseudopod but the organism as a whole may move toward the food. The diffusion, however, appears to be very slow. In simple multicellular forms, such as the sponges, trans-

mission likewise takes place. Thus, Parker states[1] that if a pin is stuck into a finger of *Stylatella* at $1\frac{1}{2}$ cm. from the osculum, the osculum will close in about ten minutes; and further, that "the sluggish transmission upon which this reaction depends represents without doubt that elemental property of protoplasmic transmission from which true nervous activity has been evolved. It may, therefore, not inappropriately be called neuroid transmission."[2] Similarly, in other animals a transmission of motion through non-active and non-nervous protoplasmic tissue can be demonstrated as when motion is transmitted from one field of cilia to another, although quiescent or non-ciliated tissues lie between. According to Parker, "it appears that the ordinary tissues of animals, at least their ciliated epithelia, may exhibit sluggish forms of transmission that are so like those seen in sponges as to admit of being classed under the single head of neuroid transmission."[3]

[1] Parker, loc. cit., p. 42.
[2] Parker, loc. cit., p. 64.
[3] Parker, loc. cit., p. 75.

II

PATHWAYS OF TRANSMISSION

Obviously, it is greatly to the advantage of an organism when special pathways for transmission are differentiated. Such pathways make their appearance in the primitive nervous apparatus of cœlenterates. This nervous apparatus has been elaborately studied in jelly-fishes and sea-anemones. In the former, impressions—stimuli—upon the marginal bodies are diffused through deeper lying muscle-cells, so that a contraction takes place in the large circular sheet of muscle that forms the sphincter-like organ midway between the centrally located mouth and the edge of the bell. This contraction reduces the cavity of the bell and by thus driving the water out of this cavity forces the animal forward.[1]

In the sea-anemones an impulse—a mechanical stimulus—applied to the surface of the animal results in a retraction of the oral disc. Investigations have shown that the impulse

[1] Parker, loc. cit., p. 103.

both in the jelly-fish and the sea-anemone is diffused through a well-defined nervous network. When this nerve tissue is studied, it is found to consist of a diffuse and continuous network which also contains cells. The fact that the network is continuous and diffuse suggests an analogy to the syncytic tissue of the dermal layer of the sponges. In keeping, however, with what one would expect, the evolution of special pathways for transmission, leads —judging by the time of the response—to an increased speed of transmission; the response, which is very slow in sponges, is much more rapid in the cœlenterates.

Let us now turn our attention once more to the primitive muscle-cell in the pore canals of the sponges. This muscle, as we have seen, suggests the smooth, unstriated muscle-cell of the higher animals; indeed, such a muscle-cell is still found in some of the tissues of the latter existing as a prototype independent of nervous influence. A muscle-cell independent of nervous influence reacts directly, as we have seen, to a stimulus applied to it. This is unquestionably the case in the muscle-cell in the pore canal of the sponge, in which the stimulus is

the flowing water and the substances contained in the latter; similar facts obtain in the case of the other independent smooth muscle-cells that have been instanced. In the sea-anemones and the jelly-fishes, however, the muscle-cell no longer receives its stimulus directly from the environment. There is now interposed an epithelial cell which receives the stimulus and transmits it to the muscle-cell. This epithelial receiving cell acts as a "sense" cell and is termed the "receptor," while the muscle-cell to which it conveys the stimulus is known as the "effector." Later a third structure appears interposed between the receiving cell and the muscle-cell. The function of the new structure, a cell termed by Parker "protoneurone," appears to be to diffuse and to distribute to the muscle-cell or cells the stimulus derived from the receiving cell. Its function is that of an intermediary. Evidently we have presented here an arrangement which is the prototype of the sensory, nervous, and muscular system of the higher animals.

Certain other important considerations now present themselves. In the higher animals the nervous system, which in sea-anemones and

jelly-fishes is largely superficial, existing in the epithelial layers of the animal, becomes gradually more and more deeply seated and better protected. This is seen in the higher invertebrates and vertebrates alike. In invertebrates there is a gradual retreat, a migration, of the nervous apparatus into the interior of the animal; in vertebrates, as evidenced by embryology, a portion of the epidermal layer, a portion doubtless corresponding to a primitive area of receptor or sensory epithelium, becomes grooved and finally inclosed by the infolding of the edges of the groove.

Interesting as these facts are, a still more important consideration remains. The nervous system of cœlenterates, as we have pointed out, consists of a diffuse and continuous network which also contains cells and which is grossly analogous to the syncytic tissue of the dermal layer of sponges. Restating the facts thus far considered, we find that the most elemental form of response by an organism to the environment—next to the movement of the pseudopod of an amœba—consists in the contraction of an epithelial cell, a cell analogous to a smooth muscle-cell, directly in response to a stimulus.

The next stage consists, as also pointed out, in the appearance of another epithelial cell which does not itself contract, but receives the impression or stimulus and transmits it to the contractile cell. In this primitive arrangement, the first or receiving cell, the receptor, is attached directly to the muscle-cell, the effector. As a matter of fact, a number or a group of receiving cells are attached to a number or a group of muscle-cells. Further, this arrangement "is complicated by the fact that the central branches of the receptive cells are not only applied to the muscle-cells, but form among themselves a network of communication whereby the impulses that arise from a few receptive cells may be transmitted to many muscle-cells instead of being limited to a restricted group."[1] The final stage consists in the differentiation of additional cells now interposed between the primitive receiving cell and the muscle-cells. The network now becomes exceedingly complicated, but it presents this distinguishing feature, its fibers are continuous. The cells which it contains are clearly primitive nerve-cells and, as already stated, Parker has applied

[1] Parker, loc. cit., pp. 200, 201.

to them the term "protoneurones." Further, there is no separation of these protoneurones from each other such as occurs in the neurones of vertebrates. There is a free interchange between them of the fibers of the network. There is therefore a wide diffusion of transmission which is totally different from the transmission along definite paths as seen in vertebrates. It is interesting to note, however, in this connection that even in vertebrates nerve nets, diffuse and continuous, are found in certain structures, namely, in the walls of the intestine and in the heart and blood-vessels. The nerve-cells found in these structures present all the characteristics of protoneurones, and as in the cœlenterates form a continuous network.[1]

It is, however, with the differentiated neurone of the central nervous system of vertebrates that we are most concerned. Here the cells which give rise to nerve-cells are in the embryo entirely distinct and separate, and it is only by developing extensions or processes that one nerve-cell comes into relation with other nerve-cells; but there is never any fusion or exchange of fibers between them. Each nerve-cell is a

[1] Parker, loc. cit., pp. 118, 128.

separate and distinct histological integer. It is a unit which is made up of the cell body and the cell processes. By means of the latter it comes into proximity with other nerve-cells often far distant. The processes terminate in brush-like tufts, basket-like formations, and in other ways. The approximated end-formations of two nerve-cells is spoken of very appropriately as a synapse. The nerve-cell, in general terms, is made up of a cell body and two kinds of processes; at one extremity are found one or multiple processes leading to the cell body; these are known as the dendrites; at the other extremity is found a process leading from the cell body; this is known as the axone. To this entire structure Waldeyer in 1891 applied the term "neurone," which has been universally accepted and is now in common use. Occasionally there is more than one axone; quite frequently, too, the axone gives off small side branches, usually near the cell body; these are known as collaterals.

For a discussion of nervous function clear conceptions of nervous structure are absolutely essential. To repeat, then, the neurone corresponds morphologically to one cell; it is an anatomical and genetic unit. It comes into

close relations with other neurones but remains anatomically distinct and separate. The point or, rather, the structure at which the juxtaposition of the processes of two neurones takes place—the synapse—assumes, therefore, a special importance in the problem of transmission.[1] Not only the independence of the individual neurone but the presence of the synapse distinguishes the nervous system of the higher animals from that of the cœlenterates, and it may, therefore, be spoken of as a synaptic nervous system in contrast with the nerve-net of the cœlenterates which is essentially syncytic.

A very important fact now becomes manifest. In the nerve net of the cœlenterates transmission is essentially diffuse in character. Only in a very limited degree is the response to a stimulus differentiated. According to Parker, a stimulus—*e. g.*, a fine glass rod—applied to a single spot on the body of a sea-anemone may be followed by a contraction of its whole musculature.[2] However, if the stimulus be less

[1] Instead of the cells coming into relation by the approximation of the end-tufts of the axone of one cell to the dendrites of another, the end-tufts of the axone of one cell may terminate about the body of the second cell, but in neither case is there any fusion or continuity of structure.

[2] Parker, loc. cit., pp. 99, 100, 207.

vigorous and limited—*e. g.*, if light be thrown on one side of the animal—it responds usually by turning its oral disc toward the light. Again, stimulation of its tentacles by food will cause its transverse mesenteric muscles to contract and thus open its œsophagus. Further, transmission though diffuse in certain nerve-nets takes place more readily in one direction than in another; *e. g.*, in the tentacles of the sea-anemone, in which transmission is much more freely accomplished in a proximal direction than in a distal one. This slight tendency to specialization in the responses exhibited by the sea-anemone is to be looked upon as the forerunner of the extremely specialized and limited responses met with in the higher animals. However, while a nerve-net may transmit more freely in one direction than another, it really transmits in all. Transmission in one direction, that is, *polarity* of transmission, exists in a very imperfect degree in the nerve-net. In the synaptic nervous system, however, it is not only established, but is absolute. For example, while it is possible to elicit a response to a stimulus applied in the course of an afferent neurone of the spinal cord, as in obtaining a

spinal reflex, no amount of stimulus applied to the efferent neurone, for instance, to the central end of a divided motor spinal root, will elicit any response whatever. Were it not for the synapses and the consequent polarity of the neurone, a stimulus so applied should diffuse to other neurones in the cord; *e. g.*, to sensory neurones and from these again to motor neurones, and thus lead to a response; but none takes place.

It is to the synaptic nervous system of the vertebrates that we will now direct our attention. We have already seen that the smooth muscle-cell of the pore-canal of the sponge responds to a direct stimulation. In the cœlenterates, a receiving cell is interposed between the muscle and the stimulus. The muscle manifests the response; it is the effector; the receiving cell is the receptor. At the next stage of differentiation, as already pointed out, another cell is interposed which now transmits the impulse from the receptor to the effector. In vertebrates this constitutes the simplest expression of a response, or, to use the physiological term, a reflex. An impression is made on the cutaneous surface; is transmitted along the dendrite

of the afferent neurone; thence to the cell body of the latter; thence along its axone to its end-tufts which are in relation with the dendrites of the transmitting cell and form with the latter a synapse; thence to the body of the transmitting cell (the motor cell in the ventral horn of the cord), and thence by the axone of this transmitting cell to the end-plate on the muscle-fiber. The mechanism of the response does not, however, remain as simple as this; for other neurones, intercalary neurones, are further interposed; thus a neurone may be interposed between the afferent cell or receptor, the sensory neurone, and the motor neurones. The effect of such an intercalary neurone may be twofold: first, it may reinforce, *i. e.*, increase the volume and intensity of the transmission; secondly, it may come into relation with neurones other than the ones between which it is interposed and thus make possible a more extensive and a more complicated response. An *a priori* consideration would suggest that there are necessarily great variations in the simplicity or complexity of the responses as well as wide variations in the degree with which such responses are fixed or stereotyped. These in-

ferences, I need hardly add, are in accord with fact. In the spinal reflexes, for instance, we have examples of relative simplicity and stereotypy of response. In the knee-jerk we have an example of an exceedingly simple and fixed response. It is invariably the same and independent of volition; it is subject, of course, to variations in diffusion and degree dependent upon secondary factors, but its character never changes. The neural mechanism upon which it depends is relatively simple.

However, the very simplicity and stereotypy of the knee reflex bespeaks a response that has become differentiated and limited, and it serves our present purpose merely as offering an example of a simple mechanism of spinal response. It is exceedingly probable that in the course of development differentiations of limited relationships between intercalary neurones and efferent neurones ensued relatively late, and that the primitive arrangement was one which permitted of the more or less wide diffusion of the stimuli received by the afferent neurones. In keeping with this we note in the fish, in response to such stimuli, movements which involve the musculature of the entire trunk. Evi-

dently the mechanism of response must at first have been very general in character. It must have consisted in the linking of intercalary neurones and the consequent formation of pathways of transmission general in character, and, furthermore, common to the transmission of stimuli received from many different receptors.

III

IMPACTS WHICH LIVING PROTOPLASM IS CAPABLE OF RECEIVING

Having laid a foundation for the conception of the mechanism by means of which stimuli are received and transmitted, let us now turn our attention briefly to the stimuli which the organism is capable of receiving. Thus far we have considered merely the most primitive of all stimuli, namely, contact with foreign bodies. Such contact constitutes an impact grossly mechanical or physical in character. Evidently, living protoplasm is, in addition, exposed to actions that are chemical, to the movements and coarse vibrations of the medium in which it is immersed, as well as to the various forces that pervade the physical world.

Protoplasm is, of course, destroyed by any chemical action that radically interferes with its structure. Living protoplasm, as pointed out, is an exceedingly complex colloid; it is relatively unstable and is constantly undergoing change. It is being constantly built up and yet is being constantly oxidized and reduced. Such

changes necessarily mean an interplay within comparatively narrow limits. If living protoplasm is exposed, for instance, to the gross action of an acid or an alkali, its destruction necessarily follows. There is, however, a wide range in which chemical action can take place without such result. Such non-destructive action would naturally be influenced, first, by the nature of the substance diffused through the surrounding medium, and secondly, by the degree of its dilution. The reaction of the protoplasm to such influences cannot, of course, be observed by us through the microscope, but that such chemical actions do take place is evidenced to us in our own persons by our senses of taste and smell. Further, it will become apparent as we proceed that the reaction of the organism to the chemical impressions of the environment have profoundly influenced the development of the nervous system.

When we turn our attention to the movements and vibrations of the medium in which the protoplasm is immersed, we at once find numerous evidences that the protoplasm reacts to such influences. In the very simplest forms, such as the protozoa, the coarse movements of

the water—currents and the like—possibly facilitate the changes implied by oxidation, but do nothing else. Soon, however, in the metazoa we observe the appearance of small cavities—vesicles—which contain one or more particles of solid mineral matter and which constitute an apparatus by means of which the movements, the vibrations, of the surrounding medium are taken up—arrested as it were—and thus forcibly transmitted to the substance of the organism. Such an apparatus, though it is termed an ear, an otic vesicle, may take up movements far coarser than those which in ourselves give rise to sound. Again, in fishes there is, in addition to a well-differentiated ear, an apparatus which extends in linear form from the head on each side of the body to the tail. It is known as the lateral line system and consists of a tube having at intervals an open space closed by a membrane beneath which is found a structure indistinguishable in its essential features from a macula acustica. Each such macula contains epithelial cells bearing hair-like appendages and each is surmounted by a small jelly-like mass containing a few granules of mineral matter. It is exceedingly probable that this apparatus,

existing as it does in addition to the ear, has to do with the reception of vibrations other than those of sound; namely, waves and movements of relatively great length.[1]

It would appear, then, that in addition to the chemical impressions of the environment, the movements and vibrations of the surrounding medium are taken up in greater or less degree by living protoplasm. These movements seem to play an indifferent rôle in the protozoa and in plant life, but in metazoa an apparatus sooner or later makes its appearance, the function of which is to arrest and to transmit, and, in many instances, to magnify what is purely a mechanical or physical impression.

Similarly, living protoplasm has the function of taking up other incident forces. Especially is this the case in regard to light. The simpler forms of life—*e. g.*, the amœba and other protozoa—are largely transparent to light. It is probable that the light vibrations so transmitted influence notwithstanding the chemical

[1] See, among others, Dercum, Proceedings Academy of Nat. Sci., Philadelphia, 1879, p. 152. The function of equilibration has also been assigned to these structures, but the fish already possesses a well-differentiated set of semicircular canals. It is probable, further, that one of the functions served by the lateral line system is to convey impressions corresponding to the changing pressures of the water at various depths.

changes in the protoplasm; indeed, this is so evident in plant life as to admit of no question. However, very early we note in many protozoa the appearance of a small mass of red or dark red pigment, a so-called eye spot or stigma, a mass which clearly is not, or is less, transparent to light than the remaining protoplasm, and whose action is apparently to arrest and transform the light vibrations and, possibly, to transmit this transformed energy to the general protoplasmic mass. Clearly we have here a mechanism, a modification of structure, analogous to the formation of the otic vesicle, the function of which with its contained mineral granules (otoliths) is obviously to arrest and transmit coarse physical vibrations.

Heat likewise greatly influences the activity of living protoplasm. The reactions of amœbæ and other protozoa to variations in temperature are well known. Whether in given forms the eye spots, the stigmata, play here also a rôle is not known, though it is, of course, not improbable. However, the presence of the stigmata is clearly not necessary to the temperature reactions of the primitive organism. All things considered, special structures for the

"taking up" of heat rays do not appear to be developed until late in the evolution of the metazoa, and our knowledge of them is largely inferential. Regarding their actual existence, however, there can be no doubt; of this our ability to appreciate hot and cold and, indeed, many gradations of temperature, offers indisputable evidence.

A very striking fact now becomes apparent, namely, that the various mechanisms for the special reception of the incident forces of the environment are exceedingly small in number· They are limited to receptors for contact, for coarse movements and vibrations of the surrounding medium, for chemical changes, and for the forces of light and heat. This is essentially the arrangement in the higher metazoa and notably in our own persons. This, however, leaves the organism without any provision for the reception—appreciation—of vast ranges of vibrations of whose existence we have in consequence only an inferential knowledge. Besides contact, touch will give us information only of coarse vibrations numbering less than 30 per second; thence, vibrations from 30 to 30,000 per second are appreciated by the ear.

Now ensues a great hiatus, for the organism is unable to appreciate any vibrations between 30,000 per second and 3000 billion per second. Vibrations from 3000 billion to 800,000 billion are appreciated as radiant heat; 400,000 billion to 800,000 billion are appreciated as light. For vibrations from 800,000 billion to 6,000,000,000 billion, embracing the ultra-violet rays and the *x*-rays, there is no appreciation whatever.[1]

When we consider the vast range and number of the forces at work in the universe, the exceedingly limited capacity of the organism to become cognizant of its environment becomes very apparent. Living protoplasm fails utterly to develop receptors for these unnumbered manifestations of energy. Protoplasm seems to be "transparent" to them. Have we not a hint here as to the structure of protoplasm? If deluged by them in great volume it may be destroyed, but as ordinarily exposed in the course of nature to electricity, the ultra-violet ray, the *x*-ray, and other rays it remains unaffected. It is very suggestive, too, that it is practically transparent to light rays and is obliged to develop a pigment, the stigma, the visual purple.

[1] Herrick, Introduction to Neurology, W. B. Saunders Co., Philadelphia and London, 1922, third edition, p. 77.

Similarly, it is largely negative to coarse vibrations and requires the development of a vesicle with its contained otolith.

In order that the significance of the above facts may be fully appreciated, let us recall to our minds once more the nature of living protoplasm. It is, as we have already pointed out, an exceedingly complex colloid, built up of many complex amino-acids distributed through varied disperse and continuous phases. It is a very unstable compound, for it is constantly undergoing changes. It is constantly being oxidized and reduced, but is as constantly being built up. Foreign materials, proteins, fats, and carbohydrates are through its fermentative (*i. e.*, chemical, electrical) action fragmented until they become identical in character with the molecules of the original protoplasmic mass and become part of its substance. During this process and in the further continuance of the chemical change, that is, in the continued process of oxidation, energy is liberated. The older particles are finally chemically so far reduced that they become inert and then spontaneously make their exit by solution into the surrounding medium. It is this continuous chemical change

with its accompanying evolution of energy that constitutes the phenomenon presented by living matter.[1]

Evidently, if so complex and unstable a compound as living protoplasm when first evolved had been vulnerable to the innumerable incident forces of the universe, it could never have survived. Curiously, it has been almost wholly negative in its reaction to these. Extremes of heat and cold, coarse physical destruction, have been the most it had ordinarily to contend with. Excessively rarely have other agencies interfered with its existence. Its very "transparency" has been its salvation. Perhaps it is its complexity, its semifluidity—its very inability to take up manifold modes of motion—its colloidal plasticity, its peculiar molecular structure, that have made possible the passage through it of such a vast array of forces without change in its substance. After all, these forces do influence it and play a rôle in its physics and chemistry, but certainly that rôle, as it occurs in nature—not in the laboratory—is not a destructive one.

[1] The mineral salts—ions of the crystalloids—undoubtedly arrange themselves during this process in accordance with electrical principles, and no doubt play an important rôle.

IV

DIFFERENTIATION OF THE RECEPTORS AND METHODS OF RESPONSE

We have already considered (see p. 30) the evolution or adaptation in metazoa of a surface cell to receive external impressions, *e. g.*, of contact, and which receiving cell (receptor) transmits the impact or impulse to a contiguous contractile cell (muscle-cell, effector) either directly or, it may be, through an intermediate cell or cells. Evidently these primitive surface cells were capable of receiving all of the impressions which the protoplasm itself was capable of receiving. These impressions consisted primarily of those of contact and of coarse vibration. That substances contained in the medium in which the organism was immersed also affected the surface cells chemically is extremely probable. It seems equally clear that the surface cells were also affected by the vibrations which give rise to sound and by those which give rise to heat and light. In both of the latter instances, however, it is evident

that the degree and extent in which the impacts could be taken up depended upon the presence of special and probably, at first, purely incidental factors; on the one hand, on the presence of coarse mineral particles, and, on the other, of particles of pigment; *i. e.*, of particles derived from the original protoplasm and so changed as to be able to arrest in a measure the incident forces.

In addition, then, let us repeat, to contact and coarse vibrations, the primitive surface receiving cell also received those impacts termed "chemical." These impacts, molecular in character, are those which, as already pointed out, give rise in ourselves to the sensations of smell and taste. It would seem that the reception of chemical impressions was almost as primitive, if not quite as primitive, a quality as the reception of contact and coarse vibrations. On *a priori* grounds we would almost expect the chemical sense or senses to have assumed a relatively high degree of importance; and this, indeed, is found to be the case, judging from the facts of vertebrate morphology. It would appear that relatively early certain receiving cells became especially adapted to receiving chemical im-

pressions and that this finally became their special and sole function. It is important, at this point, to note a distinction between the senses of smell and taste. The sense of smell is excited by objects external to the organism, usually by objects at some distance, and the impressions received from which cause the organism to approach or to move away from the object. The sense of taste, on the other hand, deals with objects that have entered the oral cavity or, at least, have come into close contact with it, and which bring about responses within the body of the animal, namely, visceral responses dealing with digestion. As expressed by Sherrington, the sense of smell is exteroceptive, while taste is interoceptive. Clearly, it is the exteroceptive sense of smell which deals directly with the environment, and as such it greatly outranks in importance the sense of taste. In keeping with this, we find in fishes that almost the whole of the cerebral hemisphere is an organ of smell, while the portion devoted to the sense of taste is much smaller and is in close anatomical relation with the portion—the visceral sensory area[1]—devoted to impressions re-

[1] Herrick, loc. cit., p. 272.

ceived from the viscera. However, in fishes the receptors for taste are found also outside of the oral cavity about the mouth and, indeed, in some forms, are rather extensively distributed externally; so that in fishes the sense of taste is not as strictly interoceptive as with ourselves, but also in part exteroceptive. The great importance of smell as an exteroceptive sense becomes evident when we reflect upon the very great range in the number and variety of the impressions, the infinitely small size of the particles concerned, and the relatively great distances at which they may be appreciated. Taste, on the other hand, has to do only with substances in immediate contact with the receptors, while the variety of impressions possible is exceedingly small; namely, merely salty, sour, bitter, and sweet. Flavors, it should be remembered, are appreciated only through the sense of smell.

Just as in the course of development special receptors were differentiated for chemical impressions, special receptors were differentiated for the reception of sound and light, and to which have been adapted various structures for intensifying and elaborating the impressions re-

ceived. A consideration of the latter factors would take us too far afield and, further, is not necessary for our purpose. Suffice it to say that highly specialized receptors with highly complex additions have in the course of time made their appearance, and that they are all expressive of a common truth, namely, that they receive and transmit into the interior of the organism certain definite impacts from the external world. That there are more than five pathways for the ingress of these impacts need not here be pointed out; the consideration of others than those thus far discussed may be safely deferred for the present.

Having emphasized the purely physical character of the rôle played by the receptors, let us turn our attention once more to the transmission of the impacts through the organism. How does the organism respond to the multitude of impressions received? What are the reasons therefore? In how far are responses fixed? In how far are they variable?

The simplest form of response, as we have already seen, is the response of a muscle-cell to direct stimulation; the next in the course of evolution is the reception by an epithelial cell,

a receptor, of the impact, and the transmission of the latter to a contiguous muscle-cell, an effector; the third state consists in the interpolation between the receptor and the effector of another cell whose function is that purely of transmitting the impact from the first cell to the second. This third cell may have relations, however, with several effectors, and thus the response induced may be less simple and proportionately extended. This intermediate cell has been termed by biologists the "adjustor." It should, of course, have a definite name, but to the writer it has seemed that the word "adjustor," implying as it does independence of action or possibly volition, is open to objection. The action of the intermediate cell is purely physical and, needless to say, automatic. Its presence, however, opens up, as we will see, enormous possibilities as to the degree and the character of the response. As already pointed out (see p. 38), other transmitting cells, intercalary neurones, are in the course of development farther interposed. The rôle of the latter in increasing the volume and intensity of the transmission and in adding to the complexity of the response we have already indicated.

Evidently the presence of the intercalary neurones has made possible the establishment of definite pathways of transmission. Impacts derived from many sources would tend to form average pathways of transmission to the effectors. To use the words of Sherrington, "That portion of the synaptic nervous system which is termed 'central' is the portion where the nervous paths from various peripheral organs meet and establish paths in common, *i. e.*, '*common paths.*'" The central nervous system of vertebrates is primitively a longitudinal tubular structure which lies above another longitudinal tubular structure upon which the nutrition of the animal depends, namely, the alimentary canal. The material admitted to the latter traverses its entire length. Evidently the reception of material which may serve as food is of primal importance to the animal. Given the "polarity" of the latter—*i. e.*, the differentiation of a cephalic and a caudal extremity—it follows that the interplay of receptors and effectors to bring about the intake of food at the cephalic end is a necessary outcome of the action of the individual receptors and the establishment of common paths of

transmission. The primitive nervous system of vertebrates was in its essentials a tube in which the nerves coming from the peripheral surfaces terminated synaptically in neurones in the walls of the tube; probably there was an arrangement in segments, certain nerve aggregations corresponding to certain areas. These tubal centers were doubtless connected with each other by intercalary neurones which communicated synaptically with each other to form "internuncial paths." In this way many muscles would probably be made to respond simultaneously or successively to an impression made upon a limited number of cutaneous receptors. If we turn our attention to the cephalic end of the animal, we note the presence of certain aggregations of neurones about the tube which stand in definite relation to certain receptors situated about the head, the relation being very much the same as the segmental relations in the tube lower down. Here, to restate the fact, definite cutaneous levels of receptors are related to the neurone aggregations at the same levels, each such arrangement constituting a segment.

The first aggregation of neurones that we meet with in the primitive vertebrate forms, is

that constituting the olfactory lobe, which is in close relation with the receptors in the olfactory mucous membrane. Back of the olfactory lobe we note the presence of a lobe related to the receptors in the eye; next an aggregation related to the receptors in the ear, and so on. Naturally these facts find their simplest expression in fishes. Speaking of the dogfish, Herrick states[1] that we may recognize in this fish a "nose brain," an "eye brain," an "ear brain," a "visceral brain," and a "skin brain." Each "brain" is related, let us repeat, to certain receptors and to these only. Further, each set of receptors and its corresponding central neurones is adapted to the reception of certain impacts or stimuli only; thus the receptors for the olfactory lobes can receive only chemical impressions; the receptors for the optic lobes only the impacts of light; those for the ear only the impacts of sound, and so on. In other words, each receptor can accept only its own special stimulus; the latter is known technically as the "adequate" stimulus.

We are impressed at once by the relatively enormous size in the fish of the olfactory lobes.

[1] Herrick, loc. cit., p. 120.

We are justified in inferring that the chemical sense in fishes is most important. Its receptors are placed immediately above the oral cavity and its function in the approach of the organism to food and in the intake of food is quite obvious. We note that the chemical impacts, *i. e.*, odors, are often received from great distances. The question arises why does the organism as a whole respond to the reception of such impacts by an approach? Here we are forced in a measure into the field of speculation. However, the phenomenon must be purely physical and therefore capable of a physical interpretation. Once more we are referred to the reactions of living protoplasm to the impacts of the external world. Evidently these impacts can be roughly divided into two groups: first, those whose motions can be taken up by the protoplasm with little or no consumption of its own substance, and, secondly, those in which the vibrations or molecular movements imparted by the impacts tend to disrupt, to disorganize, or destroy its structure. Evidently, chemical impressions which are in harmony or in consonance with the protoplasm of the olfactory receptors, or, to state it in other words,

whose chemical or physical motions are accepted and transmitted by the receptors with no or a minimal change in the protoplasm of the latter, establish a direction of least resistance. Possibly this reaction, in its essence, does not differ from that which leads the amœba to throw out a pseudopod toward a neighboring mass of food. In the latter (as we have already seen on p. 19) we have reason to believe that the phenomenon is purely physical or dynamic. This becomes the more probable when we call to mind that transmission through nerves is electrical in its nature. Electrical transmission is definitely known to be the immediate result of a physical impact (see p. 94), and if this be true, it must, to say the least, be equally true of chemical impacts. The problem, therefore, of the approach of the fish to food or of the extension of the pseudopod of an amœba is probably dependent upon the degree and nature of the ionization produced; that is, upon the chemical electrical changes in the olfactory receptors and lobes in the case of the fish and in the pseudopod in the case of the amœba.

Internuncial fibers connect the olfactory lobes with the centers lower down, namely, with the

neurones in the spinal cord which innervate the muscles on either side of the trunk. In response to an impression received primarily through the olfactory receptors these muscles contract. The neurones which supply the two sides are synaptically so related that when the muscles of one side of the trunk contract, contraction of the muscles of the other side is inhibited. The result is an alternate contraction of the muscles of the two sides, which causes the body of the animal to be propelled forward as in swimming. The neurone relationships which necessitate the alternate contractions and alternate inhibitions or relaxations of the two sides are in part direct and in part indirect through the cerebellum. With these subsidiary problems we are, however, not at present concerned.

Should the chemical impressions be harmful or of such a nature as to portend harm, it is easy to understand how reverse movements should occur and the animal be moved away. Everything depends upon the development of the internuncial paths. The latter are clearly association paths which when once fully developed respond accurately and, it is needless to add, automatically to the olfactory im-

pressions. Further, it is very probable that in the course of evolution these olfactory impressions would not necessarily be limited to those which merely affected the protoplasm of the receptors for good or for ill, but for those which affected the tissues of the organism as a whole. While the reader may find objection to the above interpretation, the fact remains, I think, beyond reasonable question that the approach or retreat of the fish in response to olfactory impressions is a purely automatic phenomenon.

When we turn our attention to the eye, the ear, and the lateral line system of the fish, other important and interesting facts suggest themselves. Thus, it is exceedingly probable that the field of vision is primarily one for the perception of moving objects rather than for those which are stationary. Food, already perceived by its odor, makes also in moving an impression on the retina. Owing to the internuncial pathways, the action of the olfactory apparatus in bringing about contraction of the muscles in swimming would now be reinforced. A similar effect would be exerted if the object also made a sound and so excited the ear, or produced coarse

waves in the water and so excited the lateral lines.

Whatever explanation we adopt, whether we consider the olfactory impacts—the chemical molecular movements of smell—as establishing a line of least resistance, or whether we adopt the explanation of these impacts as establishing an "attraction," the conclusion is alike inevitable that the resulting approach of the fish toward the food is, let us repeat, automatic. Similarly the reaction of the other "brains" to their special receptors—the eye brain, the ear brain, the skin brain—must be alike physical and automatic.

It may, I think, be safely assumed that the other functions of the fish in which the nervous system plays a part, such as digestion, respiration, circulation, and nutrition, are similarly automatic; in fine, that all the neural functions are automatically performed. The question arises can we draw a like conclusion as regards the nervous system of the higher vertebrate forms, including man? Let us see what the facts justify.

The automatic character of a spinal response or reflex must be admitted without question.

Secondly, this response is fixed and invariable. A similar interpretation must, I think, be extended to the responses which involve the brain stem, namely, the medulla, the pons, the crura cerebri, the thalamus, and the corpus striatum; indeed, the brain stem is frequently spoken of as a segmental apparatus, just as we apply the conception of a segmental apparatus to the spinal cord. It is also spoken of as the palæo-encephalon (Edinger) as it represents the primitive vertebrate brain. To the brain stem we must add the cerebellum whose activities are alike "invariable, innate, structurally predetermined."[1] This leaves us as the only structure permitting a variable response the cerebral cortex.

It may be here noted that such modifications of the invariable response as an animal betrays in its behavior under changed external conditions, such as absence or surplus of food or of oxygen, or such changes in response as may have their origin in changed physiological states within the organism itself, are not here included in the expression "variable" responses, but rather such responses as would suggest, other things

[1] Herrick, loc. cit., p. 122.

equal, a volitional act, *i. e.*, "choice" on the part of the animal. "Choice" in this sense is manifested by such elementary forms as the amœba, and, as we have seen, by the individual cells of the body tissues. How this apparent choice is to be explained on purely physical and chemical principles we have also seen. Let us now take up the "variable" responses of the higher vertebrates for detailed consideration.

5

V

THE RÔLE OF THE NEO- OR TELENCEPHALON

THE end of the primitive neural tube, the telencephalon, also spoken of as the neoencephalon, has no segmental relationships. It can, therefore, only be in relation with, and grow in relation with, the other portions of the neural tube. Its neurones in their development and multiplication can only establish relationships with the neurones of the primitive segmental brain; ingress and egress are possible only through the latter. Not having segmental relationships, the neurones of the end-brain are necessarily limited to the function of intercalary neurones. If the end-brain grows in response to the stimulus of function—and the facts of embryology, comparative anatomy, and palæontology show that it has so grown—it means that a multiplication of intercalary neurones has taken place, and, as a corollary, an increasing variability—that is, an increasing "adapta-

bility"—of response. An increasing adaptability of the responses of the organism to the constantly changing condition of its existence can only become possible through the multiplication of intercalary neurones. This multiplication permits alike of an increased complexity and an increased adjustment of the responses. Finally, it is obvious that in speaking of the function of the end-brain, the cortex, we should speak not of the variability of the responses, but of the *adaptation* of the responses.

In turn, it becomes evident that the responses of the end-brain, the telencephalon, have their origin in the relation which its neurones bear to those of the primitive segmental brain, to the neurones of the spinal segments, and to each other. Transmission into the end-brain takes place through the "between brain," the thalamus. Here we find that through the development of intercalary neurones, special way stations, nuclei, have made their appearance. In the cells of the latter various axones bearing tactile, visual, auditory, and other impacts, terminate synaptically; thence other axones constituting the so-called "sensory projection fibers" pass upward to the cortex. The nuclei in the

thalamus which play this rôle of way stations—and one of whose functions is doubtless that of reinforcement—are spoken of as "cortical dependencies"; in vertebrates lacking a corresponding cortical development they naturally have no existence.[1]

Responses make their exist from the cortex in axones which terminate synaptically not in neurones in the corpus striatum but in neurones in the brain stem and spinal segments. The latter group of axones constitute the motor projection fibers and are also spoken of as the upper motor pathway or pyramidal tract. In lower vertebrates, *i. e.*, those in whom no or a very meager telencephalon has appeared, the striatum appears to be capable in a degree of adjustable responses. This is notably the case in birds in whom the striatum is large and the cortex

[1] All of the afferent impulses, save those coming from the olfactory lobes, find their way into the telencephalon through the thalamus. It should, however, be added that in lower vertebrate forms in which the telencephalon has not yet been developed, there is an intimate relation between the olfactory pathways and the thalamus. In the higher vertebrate forms this relationship is still preserved in the habenula of the epithalamus and in the tuber cinereum and mammillary bodies of the hypothalamus; so that olfactory impacts in addition to being transmitted directly to the telencephalon are also transmitted to the thalamus and there play a rôle in association with other sensory nuclei of the latter; a rôle which will be later considered.

meager. In higher vertebrates the striatum appears to constitute a ready-made mechanism for various associated movements controlled or inhibited by the cortex. Certain it is, also, that the striatum is in part concerned in the purely dynamic function of the maintenance of muscle tone (see p. 151). It is clearly evident that in the higher vertebrates such responses as have their origin in the striatum or are transmitted by it are definitely *fixed;* on the other hand, such responses as arise in the cortex and are transmitted by the axones terminating in the brain stem and spinal segments are *variable* or *adaptable.* The responses so transmitted are adapted to the environmental happenings. They are the resultants of, and, other things equal, equivalent to, the various and multiple impacts received by the organism.

Having established the avenues of ingress and egress and having considered the nature of the responses, the question now arises, What takes place in the cortex itself? The sensory projection fibers terminate synaptically in certain regions or areas of the cortex. These areas are commonly spoken of as cortical centers for

smell, taste, vision, hearing, tactile, and other impressions. For the present it will suffice to regard them purely as gateways or avenues of entrance to the general cortex. Similarly, the neurones of a certain area—that of the ascending frontal convolution in man—give rise to axones which constitute the motor projection fibers. This leaves extensive regions which have no access to the external world either in the way of receiving impacts or of transmitting them save through such connections, direct or indirect, as they may have with the receiving or the emissive areas. The facts of anatomical structure show that there are extensive and numerous pathways—association tracts—which connect different parts of the cortex with each other. Some of these fibers form extensive and long bundles or fasciculi; others are relatively short; others still connect immediately or closely adjoining areas of the cortex. In fact, the arrangement is such that any one part of the cortex is directly or indirectly connected with every other part. Finally, extensive commissural fibers bring about an intimate union of the two cerebral hemispheres. When we reflect that the human cortex contains upwards of ten thou-

sand million neurones[1] and that each neurone bears numerous dendrites and that each neurone sends out one axone, sometimes two, and several collaterals, all terminating in numerous tuft-like subdivisions, we can realize that the number of possible combinations becomes almost infinite. That this leads to great "variability" of the response, or to restate the fact in other words, to great possibilities in the *adaptation* of the response becomes very evident. A given adaptation, as we will see later, is the resultant of the impacts received and of the previously existing cortical neuronic combinations. Finally, the conclusion is inevitable that the response to the impacts must be automatic. Such response is clearly automatic when but one neurone is interposed between a receptor and an effector, and the factors do not change when the interposed neurone becomes multiple.

A further fact now becomes apparent, namely, that as a result of a given impact a very large number of neurones may and probably do become involved in the transmission; the transmission doubtless takes place not only through

[1] According to Herrick, loc. cit., p. 28, "some 9280 million," *i. e.*, approximately 10,000,000,000.

many hundreds, but through many thousands of cortical neurones. In the course of the transmission a gateway of exit is finally reached, and thence a response is transmitted via the brain stem or cord to the effectors.

Another inference now presents itself, an inference unavoidable and conclusive, and which is of the very greatest importance; and that is, if the response is "variable," if it is "adjustable," and therefore capable of change, the neurones of the cortex cannot bear the same fixed relations to each other as do the neurones of the brain stem and cord.

Many years ago—in 1895—in thinking over the problems presented by hysteria, it occurred to the writer that possibly a hysterical paralysis —*e. g.*, of an arm—could be accounted for by a retraction of the processes of the neurones in the "arm center" of the motor area of the cortex, so that these neurones would no longer be in physiological relation with the rest of the cortex. In other words, it occurred to the writer that possibly the neurones of the cortex had some power of movement as far as their terminal processes, the dendrites and end-tufts are concerned; so that the latter could in some de-

gree be retracted or extended. An examination of the literature revealed that the idea of movement on the part of the neurone had already occurred to three other writers, one in Germany and two in France. The first to advance such a view was Rabl-Rückard,[1] who in 1890 suggested that nerve-cells have an amœboid movement; and he, at the same time, pointed out the significance of such a view in enabling us to explain the mechanism of psychic processes. His ideas attracted no attention, but in 1894 Lepine,[2] in a paper on a case of hysteria of a peculiar form, advanced practically the same theory. His idea was that the neurones were capable of movement, and to such an extent as to enable them to alter the degree of their relation to each other. Some six months afterwards another French writer, Mathias Duval,[3] advanced the same theory in a communication made to the Société de Biologie. Lepine had been unaware of the theory advanced by Rabl-Rückard, and Mathias Duval was equally unaware of the views advanced by Lepine. A

[1] Rabl-Rückard, Neurolog. Centralblatt, April, 1890, p. 199.

[2] Lepine, Revue de Médecine, Août, 1894, p. 713.

[3] Duval, Comptes Rendus de la Société de Biologie, Février, 1895, pp. 74, 86.

week after Duval had advanced his theory, Lepine,[1] before the same society, repeated his former arguments in its support. I myself presented the theory of the movement of the neurone in a paper read before the College of Physicians of Philadelphia in January, 1896,[2] and in June of that year read an address on the same subject before the American Neurological Association.[3] In the meantime, in the spring of 1896, the theory had been again advanced by two other French physicians, L. Azoulay and Charles Pupin. This view was not accepted by Ramôn y Cajal.[4] He, however, saw the necessity of admitting a change in the relations of the neurones to each other, and offered the explanation that it was the neurolgia cells which moved and not the neurones. He maintained that the processes of the neuroglia cells represent an insulating and non-conducting material, and that during the stage of relaxation these processes penetrate between the arborizations of the nerve-cells and so make difficult or impossible the passage of

[1] Lepine, Comptes Rendus de la Société de Biologie, 1895, p. 85.

[2] Trans. College of Physicians, Philadelphia, 1896.

[3] Trans. Amer. Neur. Assoc., August, 1896.

[4] Ramón y Cajal, Revista de Medicina y Cirugia Practicas, Mayo, 5, 1895, p. 497.

nerve currents; on the other hand, in the stage of contraction the processes of the neuroglia cells are retracted and they then no longer separate the processes of the nerve-cells, and the latter are thus permitted to come into contact. Evidently Ramón y Cajal admitted the very thing against which he contended, for if the nerve-cell processes are at one time not in contact and at another are in contact, they certainly move. It matters not whether the motion is an active or a passive one. Finally, while movements of neurones have not been observed in vertebrates, one very suggestive observation was made in 1890 by Wiedersheim.[1] He saw in the living animal, an entomostracan, *leptodora hyalina*, the nerve-cells in the œsophageal ganglion move. The œsophageal ganglion may in a sense be regarded as the brain of the animal, inasmuch as it receives the fibers of the optic nerve, and Wiedersheim actually saw these cells move and change their shape. He described the movement as slow and flowing and pictures in his paper the various shapes assumed by the nerve-cells at different times. While it is a far cry from the nerve-cells of invertebrate forms to

[1] Wiedersheim, Anatomischer Anzeiger, 1890, p. 693.

those of the vertebrates, the nerve-cells of the former, the protoneurones, illustrate, as we have seen, elemental truths, and the observation of Wiedersheim is in harmony with the view that the relations of the primordial neurones are not fixed as we find them in the segments of the cord and brain stem of vertebrates, but permit of change with each other. It would appear that this motility or facility of change, lost in the cord and brain stem, has been preserved in the telencephalon.

Further, we are so in the habit of looking at nerve-cells in mounted and stained sections of the cord and brain that we are apt to transfer the idea of fixation of structure subconsciously to our conceptions of the living cells and processes, and to overlook some of the marvelous truths which they present. The neurone has its origin in a simple undifferentiated cell, the neuroblast; in the course of its development, it sends out processes, some of them of enormous length, which in their growth often pass along devious routes to a definite destination. For instance, certain cells of the motor area of the cortex send forth processes, the axones, which grow through great distances to come finally

into relation with neurones in definite segments of the spinal cord; and, again, other neurones, both motor and sensory, send out processes which bring the various portions and areas of the body into definite relations with the central nervous system; that is, the axones grow out until they reach definite effectors or definite end-organs of the body surface and elsewhere. That this phenomenon must be the expression of purely physical or chemical causes there can be no doubt. Definite causes must be at work, such, for instance, as determines the growth of the roots of plants toward water. "Many organs of the adult body are known to secrete specific soluble chemical substances termed 'hormones,' which diffuse throughout the lymph or blood and call forth functional activity in remote organs. It is possible that during development of the body, the organs, as soon as definite stages of growth are reached, secrete similar substances which diffuse through the surrounding tissue and each of which has a chemotactic affinity for a certain type of developing neurones. Thus, the developing muscles may secrete a substance to which the motor neurones of the spinal cord react by a

growth of their embryonic axones toward the source of the stimulating material."[1] This phenomenon is known as chemotaxis. That in its ultimate analysis it will prove to be really electrical is exceedingly probable. (See also pp. 96, 97.)

Again, it has been found that in the course of the evolution of vertebrate forms nerve-cells change their positions. Numerous groups of cell bodies with specific functions move from their primitive positions to new locations. Our knowledge of their migration is due mainly to Kappers. It would seem that cell bodies "tend to migrate in the direction from which they habitually receive their stimuli, *i. e.*, in the direction taken by their dendrites. If there is a change in the direction from which a given nucleus (*i. e.*, a group of cells) receives its chief stimuli, the nucleus as a whole will tend to move toward the new source of excitation and away from the old."[2] The change in position is obviously expressive of a physical reaction to a stimulus, and the phenomenon has received the name of "neurobiotaxis." Both the facts of

[1] Herrick, loc. cit., p. 111.
[2] Herrick, loc. cit., pp. 111, 112.

chemotaxis and neurobiotaxis throw an interesting light on the active, living, growing character of the neurone; changing and capable of change. Indeed, capacity for change and adaptation seems inherent in the primitive neuroblasts. At times, continuous changes and fresh adaptations may be the result; at others, fixation or relative fixation may be established. There is every reason, also, for believing that the capacity for change and adaptation of the neurones is not limited to the period of development, but continues—at least as far as the telencephalon is concerned—in greater or lesser degree during the active life of the organism. Upon this, no doubt, depends the ability to acquire new and, for a time, increasingly complex adaptations; in other words, to learn, to add to, and to modify the sum total of experiences. Biological failure, senescence, and disease are the only limits to these possibilties.

Let us again turn our attention to the relations between the neurones, *i. e.*, to the synapses. Kappers[1] points out that the relations of neu-

[1] Kappers, Versuch einer Erklärung des Verhaltens an der Synapsis. Psych. en Neurol., Bladen, 1917, H. 6, p. 440; also Brain, July, 1921, p. 125.

rones to each other vary somewhat. In some the relation may be practically one of continuity, as when the neurofibrils of one neurone pass directly into those of the second; as is often the case in the vestibular apparatus. Such an arrangement may be expected in the Mauthner cell in the catfish—a large cell in relation with the vestibular nerve—in which transmission probably takes place directly between the axones of one cell and the dendrites of another. Between other cells the relation may be merely that of contiguity or, it may be added, of propinquity. At the time of the passage of a reflex a delay in transmission occurs at a synapse. Kappers thinks that differences in delay may be due to differences in the synapses. Probably this delay is greater when the histological relation consists merely of contiguity and greatest when this contiguity or approximation must first be established. The last would naturally result when a new pathway was being formed, or in the case of one that was only occasionally used. Kappers regards the transmission through the neurone in one direction only—*i. e.*, the polarization of the neurone—as a neurobiotactic phenomenon. He declares

that the formation of dendrites and axones is the result of the reaction to stimuli; the axone is a formed product of the stimuli current; it grows with the current, is formed by the current. The dendrite is likewise a formed product of the stimuli current. In the passage of the current from cell to cell, the axone terminals of the first cell are drawn toward the dendrites of the second cell, and the dendrites of the second cell are drawn toward the axone terminals of the first. The mere act of the transmission of an impulse brings about an approach, the whole process being neurobiotactic.

Sherrington[1] regarded it as improbable that the phenomena of the synapse are dependent upon an amœboidism of the neurones, and he did so for the following reason: The length of the delay caused in a reflex by a synapse—*i. e.*, the latent period—is inversely proportional to the intensity of the reflex. Sherrington found that if the latent period of a reflex produced by delivery of the stimulus in its full strength be compared with the latent period of the reflex produced in two stages—*i. e.*, by an "initial"

[1] Sherrington, The Integrative Action of the Nervous System, 1911, p. 24.

stimulus and an "incremental" stimulus—the latent period resulting in the two stimuli reflex is longer than in the first, namely, when only one maximal stimulus is applied. This result he regarded as an argument against an amœboid movement on the part of the neurones; a bridge once having been constructed by the initial stimulus, there should be no additional loss of time. However, Sherrington's results also showed that the latent period of the incremental stimulus is always shorter than that of the initial stimulus. As Kappers point out, this fact can only be explained by supposing that something takes place as a result of the initial stimulus which does not take place as a result of the incremental stimulus; and to Kappers there seems no good reason for supposing that the added time of the initial latent period is not consumed by the approach of the colloidal particles of the terminal processes. Kappers declares that the amœboidism, and, in any case, the neurobiotactic phenomena of nerve-cells, have not for a long time been mere hypotheses, but are actual facts.

The interrelations of the neurones have been the subject of much speculative thought and

study. Sherrington who, as just seen, denies the amœboidism of the neurone, expresses himself as follows:[1] "At the nexus between cells, if there be not actual confluence, there must be a surface of separation. At the nexus between efferent neurone and the muscle-cell, electrical organ, etc., which it innervates, it is generally admitted that there is not actual confluence of the two cells together, but that a surface separates them; and a surface of separation is physically a membrane."

"If the conductive element of the neurone be fluid, and if at the nexus between neurone and neurone there does not exist actual confluence of the conductive part of one cell with the conductive part of the other—*e. g.*, if there is not actual continuity of physical phase between them—there must be a surface of separation. Even should a membrane visible to the microscope not appear, the mere fact of non-confluence of the one with the other implies the existence of a surface of separation. Such a surface might restrain diffusion, bank up osmotic pressure, restrict the movement of ions, accumulate electric charges, support a double

[1] Sherrington, loc. cit., pp. 16, 17.

electric layer, alter in shape and surface tension with changes in difference of potential, alter in difference of potential with changes in surface tension or in shape, or intervene as a membrane between dilute solutions of electrolytes of different concentration or colloidal suspensions with different sign of charge."

Regarding this hypothetical membrane, Kappers is of the opinion that by a synaptic membrane we need not understand an actual membranous structure, but "merely an electro-endosmotic layer." Again, obviously such a membrane, if morphologically demonstrable, would consist of the apposition or fusion of two cell walls and, further, the physical principles involved—endosmosis and the possible passage of electrically charged ions—would apply especially to neurones with fixed synaptic relations and perhaps in less degree to neurones whose relations were changeable. In any event, it is quite probable that the physical principles involved would not differ in essence from those that determine the approach of the pseudopod of an amœba to a nitrogenous or other food particle.

Leaving for the time being the consideration

of this "electro-endosmotic layer" or synaptic "membrane" and the consideration of the physical or chemical principles involved, let us turn our attention once more to the reactions of the cortical neurone, the neurone of the telencephalon and to the stimuli, the impacts, transmitted to it from the segmental brain. In one of my earlier papers, read before the American Neurological Association in June, 1896, I thus expressed myself:[1]

"A sequence of sound vibrations impinging upon the peripheral auditory neurones produces in them a change, which in turn affects the relations which their neuraxones bear to the auditory nuclei, and secondarily to the auditory cortical neurones. Not only are the latter affected by the impressions received from the afferent neuraxones, but they, in turn, react in such a way as to change their relations to each other, and the new positions assumed by them will depend largely upon the fact as to whether a similar sequence of impressions has passed through them before. If so, the old combinations will be re-formed. From the

[1] Dercum, The Journal of Nervous and Mental Diseases, Vol. XXI, No. 8, 1896, p. 522.

cortical auditory center there now pass through the general cortex a series of combinations among the neurones, also along the oldest and best-travelled lines, so that a given sequence of musical sounds may suggest at first a familiar air, a moment later a vivid recollection of an opera once heard and seen. In this simple illustration is embraced the physiology of perception, of conception, of memory, and the explanation of the very sequence of thought itself."

Setting aside for the time being the discussion of the factors of sensation and of consciousness embraced in the above interpretation, let us take up more in detail the various other phenomena presented. First, we are impressed by the fact that time is consumed in the transmission of the impact from the moment of its reception until it finds motor expression. This is known as the reaction time. We have already briefly considered the delay which occurs at a synapse. It appears to be time consumed in the preparation of the synapse for transmission, *i. e.*, in the "setting" of the synapse (to use Sherrington's term), and which consists possibly in the formation of protoplasmic

extensions, in the passage of ions, or in the establishment of induction. Many studies have been made as to the time lost in the passage through gray matter of various reflexes, and it would appear that the simpler the reflex, the shorter the reaction time, and the more complex the reflex or response, the longer the reaction time; thus a simple spinal reflex in the frog reveals a loss of 0.008 second (Wundt) or 0.014 and 0.021 second (Buchanan), while the simplest reaction times measured in the psychological laboratories vary between 0.1 and 0.2 second,[1] and the reaction times as measured by physicians between a "stimulus word" and a "reaction word" range from one to two seconds and sometimes longer. The time consumed is evidently lost in some physical process, as already indicated. The transmission of impact from neurone to neurone means the overcoming of inertia or resistance at the beginning of each neurone, *i. e.*, at its dendrite. Each synapse, so to speak, presents a new "neurone threshold" (Sherrington).

The positions of neurones and their relations to each other are, as we have seen, determined

[1] Herrick, loc. cit., p. 104.

by the principle of neurobiotaxis. According to the latter, the dendrites are directed or, rather, are drawn toward the sources of stimulation, *i. e.*, the sources from which the impacts are received; the axones likewise are drawn toward the dendrites of the succeeding cell, and, in given instances, in the course of phylogeny even the entire neurone may move. Here we are concerned, however, merely with the behavior of the dendrites and axone terminals. No doubt the transmission, the diffusion, of an impact, to definite neurones, is determined by neurobiotactic principles, and in this is to be found the explanation of "association." In their early phylogenetic relationships the transmission of impact from neurone to neurone was doubtless determined by propinquity, and in the multiplication of intercalary neurones there gradually appeared the "common paths" (see p. 56). Definite groups of neurones, therefore, became associated in the transmission of given impacts, *e. g.*, of sound, as in the illustration quoted above. The transmission did not, however, cease in the so-called cortical center for hearing in the temporal lobe, but was transmitted along "association" paths to other re-

gions of the brain. What determines the direction of the transmission? Why do the impacts break through definite thresholds and thus give rise to certain associations? Doubtless the tendency in the primitive nervous system was to a general diffusion of impacts, but automatically, as in the instance of the establishment in the fish of the common effector paths concerned in swimming as a result of the common action of the receptors of smell, sight, and hearing in determining the approach of the fish to food (see p. 62), so impacts entering the cortex by way of the organ of hearing would probably diffuse more readily toward the cortical areas for vision than to those of touch, smell or taste, inasmuch as in the higher vertebrates impacts of sight and sound from a given source are very frequently simultaneous. That there should be a lowering of thresholds between simultaneously aroused groups of neurones would naturally follow. Activity of neighboring groups of neurones would necessarily mean an increased amœboidism. If one group only be aroused, pathways having once been established, there would be a transmission to the others which were still quiescent. At any rate, what-

ever be the explanation, it can, I think, be safely assumed that association—*i. e.*, transmission to other neurones—takes place in accordance with physical principles, and, further, having once taken place, it takes place more and more readily with repetition. In other words, to use a physiological term, it becomes "facilitated."

The special trend followed by the cortical neurones in their transmission-associations doubtless depends upon a number of factors. If the experiences are old and often met with, the same or similar associations are repeated; if they are new experiences, no doubt new combinations are formed, new pathways established. It is probably this quality of neurone activity which makes possible additions to our knowledge; it becomes thus the basis of all training and education (see p. 79).

However, the function of the neurone of the cortex is not merely that of transmission. The reception of the impact means not only the passage of the latter through dendrites, cell body, and axone, but also a change in the substance of the neurone; a change physical and chemical which results in the evolution of

energy. An active consumption of substance, probably the result of an increased oxidation, takes place, and a corresponding amount of energy is added to the impulse transmitted. It is easy to understand that when the latter finally reaches the effectors—*i. e.*, finds motor expression—it may differ greatly both in amount and character from that originally impinging upon the receptors. A very small stimulus may liberate a large amount of energy. Each neurone is a storehouse of energy which needs but the transmitted tap of the impact to release it. Evidently a series of neurones in relation with a receptor will intensify the impressions impinging upon the latter. Such an arrangement is especially evident in the olfactory lobe and doubtless accounts for the recognition by the organism of impacts so excessively minute as are those which impinge upon the olfactory receptors. Ramón y Cajal has in this connection employed the expression "avalanche conduction." Doubtless a similar truth obtains in regard to the intercalary neurones next in series, *i. e.*, those concerned primarily in the central transmission of the impact, and also and finally, in regard to those in relation with

the effectors. The retina with its multiple layers, the visual pathways and the cortical visual centers, offer parallel illustrations.

That the impact in its course of transmission through the various neurones—avalanche conduction or other—undergoes, in addition, conversions in character, is modified, transformed into different equivalents is probably equally true; but the discussion of this interesting question is deferred for the present. One truth, however, remains apparent, and that is that the 10,000 million intercalary neurones of the cortex add merely to the complexity of the response; the purely physical, automatic character of the latter remains unchanged. This automatism is as true of the higher vertebrates as it is of the lower. The reaction of the fish to the environment is clearly automatic (see p. 61), and the development of the telencephalon merely makes that automatism more complex.

VI

THE ELECTRICAL CHARACTER OF THE TRANSMISSION

It seems fitting at this point to pause and to consider the nature of the transmission of impacts. All living protoplasm is irritable; that is, all living protoplasm reacts to physical and chemical impressions. Simple illustrations, as we have seen, are presented by the amœba, the white blood-corpuscles, sponges, jellyfishes and sea-anemones, and more complex illustrations by the higher animal forms. What is it that is transmitted? What is the mode of motion that it assumes? In what form of force does it express itself? Some twenty-two years ago in a communication made to the Academy of Natural Sciences of Philadelphia, Charles K. Mills formulated the theory that nervous action is electrical in its nature.[1] Some two years later Jacques Loeb and Walther Nernst separately and independently arrived at the conclusion

[1] Restated in a recent paper before The Philadelphia Neurological Society, May 16, 1924.

that in nerve and in muscle the change from the state of rest to that of excitation is brought about by changes in the ionic concentration of the medium.[1] Lazareff has termed this the ionic theory of stimulation and upon this basis he has developed a theory of nervous excitation and applied it to the functions of the special senses, *e. g.*, of vision, hearing and taste, and of the central nervous system. Surely, if ionization lies at the basis of nervous activity, the question as to the nature of the transmission of impacts is answered. However, the physiologists have furnished us with very direct evidence. If in a preparation consisting of the sciatic nerve of a frog and the gastrocnemius muscle which it supplies, the sciatic nerve be slightly pinched, the muscle undergoes contraction. Clearly, something must pass along the nerve from the point of pinching to the muscle, and this has been demonstrated by physiologists to be an electrical change. "A spot in a state of excitation behaves as if electrically negative to a spot on the nerve at rest; that is, if the two points are connected to a

[1] P. Lazareff, Science, New Series, Vol. LIX, No. 1530, April 25 1924, p. 369.

galvanometer, a current flows through the instrument from the resting to the excited spot, as if the former corresponded to the copper of a Daniell battery and the latter to the zinc. We find that the electrical change set up at one point by a momentary stimulus lasts only for a short time at this point and passes along the nerve, making each point in turn electronegative to the rest."[1] Here an impact grossly mechanical in its nature is converted into a transmission undeniably electrical. The inference suggests itself that this result follows the incidence of every impact of whatsoever character which the organism is capable of receiving. These, as has been pointed out in the preceding pages (see pp. 42–48), consist of contact, coarse movements and vibrations of the surrounding medium, chemical changes, light and heat. It would appear that all of these modes of impact are attended by changes in ionic concentration. For instance, according to Lazareff, such changes are induced in the individual cells of the retina by actual impact. Light, he reminds us, according to the present

[1] Bayliss, Principles of General Physiology, Third Edition, 1920, p. 379.

conception of the physicist, possesses a corpuscular structure and there exists, as it were, a number of small balls, each carrying a definite quantum of energy on striking the retina.[1]

Certainly the inference seems justifiable that all nervous transmission, in fact, all nervous activity, is electrical. If this be true of the adult nervous system, it must necessarily be true of the developing nervous system as well; indeed, it must play an all-determining rôle in the latter, a rôle which begins with the very first appearance of the neuroblasts. Kappers (see p. 78), in his consideration of neurobiotaxis, points out that nerve-cell bodies tend to migrate in the direction from which they habitually receive their stimuli; the dendrites naturally assume the direction from which these stimuli are received; and in the course of development entire cell aggregations may, as we have seen, change their position. Kappers believes this to be expressive of an electrical reaction; the dendrites are actually attracted—drawn—in the direction of the stimulus. Indeed, in a recent lecture[2] he suggested the term

[1] Lazareff, loc. cit., p. 37.
[2] Delivered in Philadelphia in May, 1924.

"neurogalvanotaxis" as possibly more descriptive of what actually takes place than neurobiotaxis. We have here a ready explanation not only of the behavior of dendrites and cell-bodies but also of the course taken by the axones (see p. 81). Necessarily, the attraction between the dendrites and axones of cells placed in serial relation—*i. e.*, between the end-tufts of the axone of one cell and the dendrites of another—must be mutual. Such a relationship having once been established persists and is maintained, no matter what the exigencies of position the developing organism may demand, no matter how much the axone must increase in length, and no matter how devious the course which the axone is found finally to have assumed.

The interpretation of nervous transmission as electrical lends an added significance to the synapses. The latter have all the force and value of the Pupin inductance coil, for they both reinforce and facilitate transmission; and, just as in the case of the Pupin inductance coil inserted in the telephone wire, the presence of the synapse in the nervous pathways of vertebrates results in an enormous economy of energy. Thus the interrupted synaptic nervous

system of vertebrates enjoys an inestimable advantage over the nervous system of invertebrates, dependent as the latter is upon continuous and unbroken lines of transmission. We have here simply a repetition of the story of La Grange's weighted string.[1]

The high degree of differentiation of the adult neurone, with its complex dendrites and axones and the definite relations which these cell processes have established with other structures, makes cell division and reproduction by the adult neurone impossible. In keeping with this fact, it possesses no centrosome. However, this is not true of the epithelial tissue in which the neuroblasts have their origin. Epithelial tissues reproduce with great ease and readiness, and the facts of embryology, comparative anatomy and palæontology—as already pointed out (see p. 66)—leave no doubt that the neurones, in response to the stimulation of function, have greatly increased in number in the higher vertebrates. This is strikingly evident in the telencephalon.

Again, it is definitely known that in the or-

[1] See Michael Pupin, From Immigrant to Inventor, Charles Scribner's Sons, New York, 1923, p. 330.

ganism at birth neurones exist in large number which have not established definite relations with other neurones. Such relations are, however, subsequently established in response to the stimulus of function; *i. e.*, in accordance with neurobiotactic principles. The establishment of such relations is a gradual and continuous process. The question arises, how long does this process continue? At what point in the life of the organism does it cease? Is there not good reason for believing that it continues long after maturity has been reached; indeed, until the period of senescence has been entered? If this process were not continuous and persistent, if it were not greatly prolonged, the education of the child and youth would be impossible, while those in the mature and later periods of life would be unable to add to their knowledge or to add further to their experiences in any way.

VII

CONSCIOUSNESS

A DISCUSSION which can no longer be deferred is that of consciousness. In a consideration of nervous phenomena, the problem of consciousness of necessity obtrudes itself, and, although in a study of the simpler forms it may be ignored, it must finally be squarely faced. When we turn our attention to the protozoa and more especially to the amœba, we realize at once that a discussion whether such an organism is conscious, whether it has sensation, feeling, a sense of being, becomes futile. We have seen reason to believe (see pages 18, 19) that the reactions of the amœba to the environment, like that of the white blood-corpuscles and the other individual cells of the metazoa, are due to purely physical and chemical causes. If such structures have a sense of being, it must be one that is shared by the substance and energy of the universe generally; indeed, it must be participated in by that ultimate expression of substance and energy, the

electron itself. Are we to infer that "sentiency" makes its appearance when the combination of a given number of amino-acids results in the formation of a substance that is the seat of a continuous chemical change featured by a simultaneous upbuilding and reduction (see p. 48), a continuous change that is itself a direct result of its reaction to its environment? or, are we to defer this conception of sentiency until special arrangements for the reception and transmission of impacts make their appearance? The difficulty increases when we approach the more complex metazoa. In the contemplation of the cœlenterates we may be content to set aside the question of "feeling," but are we justified in doing this in the case of insects with their obviously complex sense organs and central nervous aggregations? Again, are we justified in assuming that the cuttlefish in spite of his elaborate eye does not "see," has not "light sensation" of some kind or other? Assuredly it is unphilosophical to assume that the fish in spite of its enormous olfactory brain does not "smell," or being possessed of eyes and ears, that it does not "see," does not "hear." True, the impacts received by the "nose brain," the

"eye brain," the "ear brain," and the "skin brain" are all transmitted into the common paths concerned in swimming, *i. e.*, in bringing about automatic approach to or withdrawal from objects in the water; yet, though the "eye brain" may glow with the sensation of light and the "ear brain" ring with the sensation of sound, the consciousness of the fish must be something very different from that experienced by ourselves. In what does this difference consist? Evidently it concerns the function of the telencephalon.

Let us for the time being turn our attention to the responses to impacts in the higher vertebrates. In amphibians the situation has changed but little from that in fishes; the responses are still the invariable, non-adjustable responses of a segmental brain. The same may be said of reptiles; variable or adjustable responses are negligible factors. When we turn to birds, the situation has apparently slightly changed. In addition to their very remarkable and complex automatic "instinctive" responses, there appears to be a capacity, though an exceedingly limited one, for adjustable responses. In birds the pallium—the cortex of the telen-

cephalon—is still very rudimentary, and if the bird does any "thinking" he must do it with his thalamus and striatum. That he does very little is quite evident from the behavior of birds ordinarily; that he exceptionally does some is equally evident from the occasional behavior of certain birds, *e. g.*, the parrot. The fact that certain birds are capable of a degree of artificial training is indubitable proof that in them the palæoencephalon has in a measure the function of adjustable responses; the pallium itself is very poorly developed. Further, it is exceedingly probable, as we shall see later on, that the complex instincts of birds, as well as those of mammals, had their origin in adjustable responses.

It would appear that the structure of the primitive brain, the palæoencephalon, the segmental brain, as we term it, is of such a character as to permit of adjustable responses in only a limited degree. However, that such adjustable responses did take place in it originally and still do take place in it in birds and perhaps in lower forms, though in very small measure, is, as we have seen, exceedingly probable. In mammals, however, the function of the segmental brain, like that of the spinal

cord, is limited to non-adjustable responses. Like the spinal cord, the segmental brain has been reduced to a fixed mechanism. Such capacity for variable or adjustable responses as it may have originally possessed has been usurped by the telencephalon.

Whatever may be the state of consciousness in vertebrates other than mammals, it is quite certain that in the latter fixed responses play no rôle in consciousness; this is true of the responses in the spinal cord, and it is doubtless equally true of the responses in the segmental brain. Here again the telencephalon has played the rôle of usurper, for the function of consciousness, as *we* know it, is limited to the telencephalon.

When we now turn our attention to this function of the telencephalon, the following interesting facts and inferences present themselves. To begin, various acts themselves the outward expression—the effector result—of the intercalary function of the telencephalon, and which when first performed are attended by consciousness, may lose this quality when frequently repeated. Acts the performance of which is at first accompanied by a conscious

effort, may by frequent repetition become largely and in some instances wholly "automatic," *i. e.*, may finally be unattended by consciousness either in whole or in part. Many of the acts acquired in early life—the use of utensils in eating, the adjustments of clothing, the movements of writing, the movements concerned in playing a musical instrument—are all acts usually at first performed slowly and with difficulty, but later with increasing ease until consciousness no longer enters into them. The same movements frequently repeated necessitate the constant repetition of the same association—the same combination—among the neurones, and sooner or later the movements acquire all the character of *fixed* responses.

The first inference that is justified is that consciousness disappears in proportion as fixation is established. Fixation of response means the disappearance of consciousness. This inference leads to another no less interesting, an inference that follows as a corollary, namely, that consciousness is present only in the "adjustable" responses; that is, only in those responses which are attended by a changing, an actively varying relationship among the neu-

rones. An impact transmitted from the cord and segmental brain into the telencephalon brings about definite changes in the synaptic relations of the neurones to which the impact is first transmitted. Thence the impact is transmitted to other intercalary neurones, indeed, to many series of the latter in the manner already indicated. The transmission of the impact, subject to reinforcement, may continue until motor centers—*i. e.*, until neurones in relation with motor neurones of the segmental brain or cord—are reached, when an outward or motor expression results; or the transmission may continue to diffuse variously through the cortex without a so-called motor area being involved. Whatever the course of the transmission, it is inevitable that the neurones concerned are involved in sequence. The axone-terminals of the first neurone approach and are approached by the dendrites of the second (see p. 81). The second neurone effects a like synaptic approach with the third, the third with the fourth, and so on. It follows that just as soon as an impact has been transmitted by a neurone—*i. e.*, just as soon as it has completed its discharge (see p. 90)—its axone ter-

minals and the dendrites of the receiving cell are again retracted, *i. e.*, the synaptic relationship is broken and the neurone is again at rest. It is, I believe, a legitimate inference that a neurone at rest can have no relation with consciousness; a neurone at rest, so to speak, is unconscious. It follows, therefore, that consciousness is only present in the neurones that are actively concerned in transmission. Consciousness is itself a phenomenon of cortical transmission.

Let us at this point consider some of the elemental facts of consciousness as they reveal themselves to our individual experience. Whatever consciousness may be, it is something that is constantly changing. A sensation, a perception, a thought is experienced. A sensation persists as long as the impacts that give rise to it continue; a perception as long as the object perceived throws its impacts upon the receptors; a thought resolves itself into a train of sequences. Each individual instant of time, however, whether it is concerned in a momentary sensation derived from a single impact or whether the sensation be made up of many succeeding instants of impacts, becomes past history the

moment it is experienced; it immediately enters the past. The same statement applies, of course, to a perception, to a thought; in fact, to any mental process. While consciousness is constantly changing from the immediate present to the immediate past, it is of necessity also constantly passing into the immediate future. Bergson[1] expresses the same facts as follows: "For consciousness there is no present, if the present be a mathematical instant. An instant is the purely theoretical limit which separates the past from the future. It may, in the strict sense, be conceived, it is never perceived. When we think we have seized hold of it, it is already far away. What we actually perceive is a certain span of duration composed of two parts—our immediate past and our imminent future."[2]

Surely these elemental facts are in accord with the principles governing transmission through the cortical neurones. This transmission is a progressive, continuous thing; receding from the point of entrance of the impact and at

[1] Bergson, Mind Energy, transl. by H. Wilson Carr, Henry Holt & Co., New York, 1920, p. 8.

[2] Thus far only is the writer in accord with Bergson's interpretation of consciousness. From this point on Bergson enters a maze of mysticism.

the same time continuously advancing. In considering transmission, however, it is important to bear in mind that in addition to the mere fact of transmission there is the further fact of the release of energy (see p. 91), a release in which each neurone successively takes part. As a result, an impact, thus continuously reinforced, becomes widely diffused. This diffusion, however, does not take place indifferently in all directions, but in accordance with definite principles. To begin with, it is obvious that transmission follows the direction of least resistance. Evidently the latter will be in the course of the most frequently travelled paths, those paths in which the amœboid approach of axone terminals and dendrites has been most frequently established, or, to phrase it in other words, in which "synaptic resistance" has been most frequently overcome. Further, it is probable that the transmissions, other things equal, at first followed the most direct routes to the gateways of exit; the demands for adjustment of the responses to the environment were in the primitive mammalian forms doubtless relatively simple; as they are to this day in moles and rabbits, insectivora, rodents, and the like.

However, the organism in response to the increasing demands made upon it by the environment, reacted by increasing its power of adaptation; it underwent, as we say, evolution.

The telencephalon grew, its neurones became more numerous, and its power of adjusting to the environment the responses it transmitted was correspondingly increased. Numerous "association tracts," great and small, gradually made their appearance, so that every part of the cortex became connected with every other part (see p. 70). Notwithstanding this increasing complexity and increased power of adjustment, notwithstanding the great facility for intercommunication, an impact entering the telencephalon is not diffused universally throughout the entire cortex. Doubtless dependent upon the nature of the impact—the exciting cause—and the special environment in which the organism happens to be placed, as well as upon other factors already considered (see p. 89), the transmission pursues a course more or less defined. The transmission is not, however, entirely limited to this course, for the neurones successively involved doubtless discharge their energy not only into those in the direct path-

way of the transmission but also into neighboring neurones not directly concerned. There is, so to speak, a lateral transmission, but one of less dynamic power, and which finally dies out within a variable range of the primary activity. Consciousness follows the main train, but also includes a limited and fading field to either side —to all sides, one might say. In a sense, consciousness is analogous to the visual field with its sharply defined central vision and its gradually fading peripheral areas. The "field of consciousness" becomes less and less distinct as the main train of activity—perception, thought, emissive impulse—is departed from. Gradually it fades into the subliminal, the subconscious, the unconscious.

Again, the "train of activity" is continuous, unbroken, during the waking period. Further, the inpour of impacts is incessant, and a given "train" may be reinforced, deflected, or modified in various ways. Cessation of the "train of activity" means, of course, cessation of the synaptic transmission, a discontinuance of the "amœboid approach" of axone terminals and dendrites. Such a discontinuance means unconsciousness and, physiologically, sleep. In

one of my papers,[1] read in 1897, I expressed myself as follows: "Evidently the neurones when functionally active must be in relation with each other. Their processes must be either in contact or nearly so. Evidently this condition is a prerequisite of consciousness. Now what happens when the nerve-cells are exhausted by fatigue, when their volume and their cell contents have been diminished, as we have every reason to infer is the case, from the experiments of Hodge? Evidently their processes become retracted and they are no longer in relation with each other. The neurone isolated from the rest by retraction must be without function. General retraction of neurones must mean absence of function, must mean unconsciousness, must mean sleep. In other words, in sleep the neurones have their processes retracted; in consciousness their processes are extended."[2]

[1] Dercum, Application of the Theory of the Movement of the Neuron, Univ. Med. Magazine, April, 1897. See also C. L. Dana, J. A. M. A., April 24, 1920, p. 1141.

[2] Lugaro's suggestion that during sleep there is a general diffuse extension of all nervous processes instead of a retraction would substitute activity for rest, and is, so it would appear, dynamically inconsistent with arrest of function.

VIII

THE FIELD OF CONSCIOUSNESS

Let us turn our attention to some of the other considerations that present themselves. Evidently the extent of the field of consciousness must depend upon the number of neurones called into activity, and this, in turn, must depend upon the impacts received, upon the number, intensity, and character of the latter. Further, it is the summation of the activities of all the neurones aroused at a given time which constitutes at that time the conscious individuality. The latter must, therefore, be regarded as multiple, as made up of many integers, and of varying from time to time both in extent and character. The group activity, the united activity of many neurones gives rise to a community of consciousness, a sense of self as something distinct from the outside world. We have here the birth of the "ego." A discussion of the degree with which man shares this property with other animals

would be nugatory. Its possession, however, by the latter to any extent must depend upon the presence of "variable," that is, "adjustable" responses. Without these a sense of self would obviously be impossible. Further, this "community of consciousness" must necessarily vary in extent from time to time within physiological limits; that it varies greatly in pathological conditions we will see later on.

The community of action of the cortical neurones must inevitably give rise to the function of memory. To make my meaning clear let me use the following illustration: A sequence of sound vibrations impinges upon the auditory receptors and in due course the impacts are transmitted to the "auditory center" in the temporal lobe of the cerebrum. Here the neurones assume relations with each other corresponding to the impacts received, the character, intensity, and other qualities of the latter; the impacts are also transmitted to neighboring and possibly distant areas. If a similar series of impacts has been transmitted by the neurones before, similar or the same combinations will be re-formed, and as a corollary there will follow a recognition by the neurones concerned in the

communal relation of consciousness as something experienced before. That memory is a purely dynamic function there can, I think, be no question. The capacity for memory must depend upon the facility among the neurones for re-forming old combinations, and this facility must be increased by repetition. In a sense memory is the expression of the same tendency to fixation of neurone combinations as has given rise to the fixed relationships in the palæo-encephalon. Perhaps some of the "instincts" and "race memories" have their basis in combinations of such frequent recurrence in the ancestry that they have acquired all the potentiality of inherited structure (see Chapter XIV).

One of the most instructive phenomena illustrating the dynamic character of memory is that presented by memory temporarily delayed. It is a matter of common experience that a name which cannot at once be recalled appears in consciousness after the lapse of a fraction of a second or, indeed, at times after the lapse of many seconds, and at a time when the train of thought is already occupying another channel. It would seem that the impact leading to the memory recall had set in motion a group of

neurones along paths only occasionally used or long unused, or along paths subject for the time being to synaptic resistance. The significant facts are that *time* is required for the act, and that the presentation of the name occurs *automatically*. Another significant illustration of the dynamic quality of memory is offered by the abnormal memory occasionally observed in certain defective children, the so-called "idiot savants." The latter may be able to give citations at great length of matter which they have heard only once and of the meaning of which they have no comprehension; not infrequently such citations are in foreign languages, of which the child is likewise ignorant. Such abnormal memories suggest a pathological tendency to fixation of the combinations; perhaps a disease of the synapses. Further, it is not improbable that in these children the tendency to fixation of the cortical responses is directly related to their idiocy. It would appear that a certain plasticity, release, and freedom of combination are essential to normal function. Even in persons otherwise normal unusual memories are often associated with decided limitations of other mental functions. Finally, it becomes quite clear

that such metaphysical abstractions as "images" and "engrams" have no place in physiology.

Referring again to instincts, it is not improbable that some instincts are inherited modes of reaction to the environment that had their origin in responses which early in the phylogeny of the race were adjustable and which, owing to constant repetition, became fixed and relegated to the subconscious field. However, other phenomena apparently instinctive are doubtless due to the mere physical reaction of the organism to the environment as pointed out by Jacques Loeb.[1] In these reactions, likewise, the responses being fixed, they play no rôle, or at most only an indirect rôle in consciousness (see p. 172).

In our discussion of the transmission of impacts through the telencephalon, and especially in our discussion of memory, we have already laid the foundation for the explanation of various detailed mental phenomena such as perception, apperception, association as expressed in the train of thought, and the transmission of the impact through the avenues of exit to the

[1] Jacques Loeb, Forced Movements, Tropisms, and Animal Conduct, Lippincott Co., Philadelphia, 1918.

effectors. In the act of perception the neurones of the cortex which are the recipients of a given series of impacts form combinations among themselves corresponding to the impacts received. The transmission, of course, does not cease here, but continues, as already indicated, by association, intracortical and subcortical, many neurones being called into activity. The combinations successively formed are some of them new, others are combinations which are the same as or similar to combinations formed upon previous occasions. The result is that the incoming combinations resulting from the act of perception assume relations in part to past combinations and in part to combinations wholly or partly new. In other words, it is the function of the common or community consciousness of the neurones concerned in this activity to collocate the impression received. It is this which constitutes the act of apperception. The train of thought automatically follows. The very act of collocation constitutes the train of thought. It *is* thought, no matter how diversified or complex the transmission may become. If it finally eventuates in a discharge through an emissive gateway, its further pro-

gress to the effectors is, of course, outside the field of consciousness.

It is evident, let us resume, that the neurones of the telencephalon are roused into action by the impacts transmitted to them from the segmental brain. As a result, the neurones involved in a given transmission extend their processes and enter into synaptic relations with other neurones, into which they also discharge. It is the active neurones alone, as already pointed out, which are concerned in consciousness. Those which are quiescent are those into which transmission has not taken place, and consequently cannot manifest consciousness. In contrast with the field of consciousness, they therefore occupy the unconscious field. It is further evident that in the progress of a transmission through the cortex, neurones previously quiescent and therefore in the unconscious field are brought into action and now become part of the conscious field, and at the same time other neurones through which transmission has been completed again become quiescent and lapse into the unconscious field. In other words, the conscious and unconscious fields are constantly changing; that which at one moment is con-

scious field at the next moment is unconscious field, and vice versa.

Again, when a transmission passes through a group of neurones, the latter react by forming combinations among themselves corresponding to the impacts received (see p. 85). A repetition of the same or similar impacts means the re-formation of the same or similar combinations (see p. 90). This implies the establishment of pathways of least resistance, and it would seem that a single transmission of an impact is sufficient to establish such a pathway. In other words, the passage of transmissions establishes "associations" among the neurones. These are manifest only when the neurones are active, and are merely potential when the neurones are quiescent. It would appear that when the latter are stimulated by a transmission, previous combinations are automatically reproduced. In this lies, I believe, the explanation of the physiology of the unconscious field.[1] The latter is a vast storehouse of past experiences. These are represented not by gross changes of structure, but merely by po-

[1] I do not like the expression "unconscious mind"; the words are self-contradictory.

tential possibilities. Whether certain combinations—associations—are re-formed depends entirely upon whether the neurones concerned are reached by a given transmission.

Further, it is, I believe, a legitimate inference that the number of neurones in action at a given time is an exceedingly small part of the sum total of the neurones of the cortex. It is very probable that the number concerned in the field of consciousness—in the train of transmission, in the train of thought—is relatively insignificant when compared with the ten thousand millions of the total. Finally, when we consider the number and complexity of both the axone terminals and of the dendrites, and the fact that every part of the cortex is in relation with every other part, we can perhaps form a faint conception of the practically limitless possibilities of association. Not only may the latter consist of combinations representing impacts the same as or similar to impacts already transmitted, but also of combinations entirely new. The organism is constantly exposed to new and changing relations to the environment, and to these demands the organism reacts by a constant readjustment in its responses. The

individual from infancy on, from his very earliest experiences, throughout his training and education, up to the complex experiences of adult life, is constantly making fresh adjustments, *i. e.*, new combinations, new associations among his neurones.

There can be no doubt that the power of the continued making of new combinations differs in individuals. In the larger number the combinations that are formed resemble those that are formed by other individuals under the same circumstances, *i. e.*, who are exposed to the same impacts. In others, a relatively small number, the combinations differ in a degree, sometimes slightly, sometimes widely, from those formed by the average individual. It is the novel character of the associations formed among the neurones that constitutes "originality." If the novelty of the association be very pronounced, it gives rise to "imagination"; originality and imagination are close kin.

The field of consciousness—*i. e.*, the train of transmission—is, of course, of relatively greater dynamic power than the unconscious field into the neurones of which it successively discharges. Whether into the field of activity itself fresh

impacts, impacts derived from other sources than that which originally gave rise to the transmission, find entrance, is purely a question of dynamics. If the dynamic level of the active field be relatively high, the ingress of disturbing impacts is excluded and the original transmission pursues its way undisturbed and untrammeled. In such case, it is open only to impacts derived from the same source that gave rise to it and which continually reinforce it. It is this which constitutes "attention." Lack of attention, the inability for sustained attention, is due to the ingress of interfering transmissions and, other things equal, is expressive of a lower dynamic level—*i. e.*, of weakness.

Similarly, the relatively high dynamic level of the conscious field especially when joined with novel associations gives rise to "initiative," to the outward expression, to the discharge—through the emissive gateways—of the cortical energy. Between "initiative" and "will" or "will power" there is again a close kinship. Given the exclusion of interfering transmissions as in attention, or in that higher degree of attention to which we apply the term "concentration," and given a high dynamic level of the

train of transmission—the field of consciousness—"will power" is the necessary outcome. The dynamic level of the field of consciousness —*i. e.*, the output of energy—must inevitably depend upon the intensity of the metabolic processes, the chemical changes, going on in the substance of the neurones and upon the number of the neurones taking part.

To the conception of the purely automatic character of the phenomena of transmission, of the amœboid movements and the serial discharges—in short, of the physico-chemical, *i. e.*, electrical changes, which constitute the train of consciousness, we must now add another, or rather recall to our minds a quality of the neurone already in part considered. Consciousness implies "sentiency" (see p. 101) as a property of the neurone. Consciousness without this property would cease to be consciousness. Sensation is a self-evident condition of consciousness and is inseparable from it. Now we have already considered some of the fundamental reactions of living protoplasm to the incident forces of the environment, the gradual evolution of special receptors, and the evolution of special portions of the primitive brain, the "segmental

brain," into which the impacts are transmitted. These are differentiated in the fish into an "olfactory brain," an "eye brain," an "ear brain," a "skin brain" (see p. 58). The inference becomes unavoidable that these structures respectively experience the sensations of odor, light, sound, and touch (see p. 101). The question now arises what rôle does the telencephalon, the great usurper, play in this respect. From the evidence of structure, only one inference is possible, namely, that the impacts from the various receptors are transmitted to the cortex. If transmitted to the cortex they must be still farther transmitted, diffused, according to the principles indicated in the preceding pages. We have no reason to infer that the mode of motion of the impact is thereby changed, *i. e.*, in passing from the neurones of the segmental brain to those of the telencephalon, or in the passage from the gateway of ingress to other areas of the cortex; and, if this be true, it can only be that sound, for instance, is experienced in every neurone reached by the transmission; or light, or smell, or touch, as the case may be. When, as is frequently the case, transmissions are received simultaneously from several special sense

receptors, the impacts do not interfere with each other. Both the sound and the object that produces it may be perceived at the same time; one through the receptors for hearing, and the other through the receptors for vision. Corresponding neurone associations, as already indicated, are formed. So it is doubtless when the impacts are received from many receptors; for instance, of sound, sight, smell, taste, touch, all at the same time. This would seem to be a necessary result of the elemental reactions of protoplasm to the incident forces of the environment; a matter which we have already fully discussed (see p. 41 et seq.).

It would appear to be a logical conclusion that, in a sense, the entire cortex sees, hears, smells, tastes, and feels wherever it is traversed by the transmission; for instance, the work of the association areas would not be possible if the neurones of these areas were incapable of taking up all the modes of motion corresponding to the various impacts. The so-called cortical centers appear merely to be avenues of ingress and egress to the general cortex, as already pointed out. To be sure, the cortex varies in its different parts in its detailed structure and

presents peculiarities in both the receptive and emissive areas; *e. g.*, in the "visual area" in the occipital lobe and in the centers of the "motor area." Here peculiarities of structure are found whose function in part is apparently that of the reinforcement of transmissions, *i. e.*, the production of "avalanche," or maximal effects. It should be added that the various portions of the cortex reveal structural differences, which, there is reason to believe, are related to the modes of impact habitually received, to the combinations and integrations of the impacts transmitted from the various areas of ingress and, finally, to the function of discharge subserved by the motor area. However, the neurone of the telencephalon appears to have retained along with its lack of fixation, along with its amœboid movement, the general elemental qualities of the primitive neuroblast, elemental qualities which are shared by the entire cortex. Other things equal, this lack of fixation of function, like the absence of fixation of the neurone itself, appears to have been and still is a necessary condition of its continued evolution. Differentiation and specialization, therefore, while it has taken place in the cortex, has not interfered with the continued adaptation and

adjustment of responses and the continued forming of new associations or combinations. Sensations are only experienced by the neurones taking part in the transmission, and these sensations doubtless depend for their kind upon the special receptors by which the impacts are received. The kinds of impact are much more numerous than would be implied by a consideration merely of the senses of smell, taste, vision, hearing, and touch. There are, first, the subdivisions of vision; namely, the perception of moving objects, of form, and color; secondly, the addition to the receptors for hearing of those for equilibrium and sense of position, and, lastly, the addition to touch of the senses of pressure, temperature, and pain.

In addition to the receptors which receive impacts from sources external to the body, there are receptors which receive impacts arising within the body. Sherrington, as already stated, has termed the first "exteroceptors" and the second "interoceptors." Besides these there is a third group of receptors situated in muscles, bones, and joints, which give information as to the state of these structures when the parts concerned are moved. These Sherrington has termed "proprioceptors."

IX

THE RÔLE OF THE THALAMUS

Other important considerations now obtrude themselves. These deal, first, with the elementary sensations evoked by the various modes of impact; secondly, with the interplay and summation of these sensations; and, thirdly, with the rôle which these factors play in consciousness. We have already considered some of the basic facts which underlie the reception and transmission of the impacts which give rise to the elementary sensations; namely, in the case of contact, in the case of the chemical senses smell and taste, in the case of light, and in the case of sound. We will recall that transmission from each group of special receptors leads to a corresponding special aggregation of neurones. These aggregations, as we have seen, are in primitive forms arranged approximately in series—as instanced in the brain of the dogfish—namely, a nose brain, an eye brain, an ear brain, a visceral brain, and a skin brain (see p. 58). Ob-

viously the correlation of diverse impacts would be greatly facilitated if these aggregations or their nuclear representatives could be grouped together in one structure; and this is what actually occurs. We find it in what is primarily the sensory portion of the segmental brain, the palæoencephalon, namely, the thalamus or diencephalon; or between brain, as it is also called. In the higher animals of the vertebrate series, it lies literally between the midbrain (corpora quadrigemina and cerebral peduncles) and the telencephalon. It has already been briefly spoken of (see p. 67). Like the striatum (see p. 150), it presents an interesting and instructive history.

Like the striatum, it is made up of an ancient and a relatively recent portion: a palæothalamus and a neothalamus. Very early we find that fibers from the olfactory pathways join nuclear aggregations in the older portions, both in the part known as the epithalamus (in the habenula) and in the part known as the hypothalamus (in the eminences back of the optic decussation and in the mammillary bodies). These nuclear aggregations are in close relation with nuclear aggregations which receive the impacts for taste

and with other aggregations which receive impacts from the viscera and from the body generally. In the newer portion of the thalamus, nuclear aggregations have made their appearance which are receiving stations in the pathways of touch, pain, temperature, and other somatic sensations, together with aggregations which are receiving stations in the pathways of light and sound. These various nuclear aggregations are especially interesting, because in the course of evolution they have been advanced from lower levels in the segmental brain to the higher level of the thalamus and thus come into more immediate relation with the telencephalon; for instance, in the case of the pathways for the light impacts, the transition has been from the anterior quadrigeminal bodies, which form the center—the final receiving station—for light in reptiles and birds, to the pulvinar and lateral geniculate body in the thalamus. Similarly a transition from the ancient center for hearing in the posterior quadrigeminal bodies has taken place to the median geniculate body of the thalamus. The explanation of these transitions is doubtless to be sought in the principle of neurobio-

taxis (see pp. 78, 88). Probably they took place gradually and in the formative and embryonic periods of the ancestral forms. What was the attracting cause? Was it the closer and more intimate reactions brought about by that other newcomer, the telencephalon? or was it the presence of the other and older nuclear aggregations in the thalamus with whom a constantly increasing interchange was taking place, and with whom a closer biotactic relationship was brought about by movement into the thalamus? Possibly and very probably both causes were at work. A dominating influence is apparently to be ascribed to the telencephalon, but the fact that most concerns us here is the grouping together in the thalamus old and new of nuclear aggregations in close relation with each other, which receive *all* of the incoming transmissions of whatsoever character; all are, so to speak, assembled here.

What is the rôle that the thalamus plays in consciousness? Clearly this rôle must be of very great importance. Consciousness is of course inseparable from sensation (see pp. 101, 102). A separate sensation, however, such for instance as a mere ringing in the ears or a mere

glow of light, with nought else, can hardly give rise to a sense of existence. The same is probably true when the sensations are multiple, if they remain unassociated. Even if associated, as in fishes, sufficiently to permit of responses along common paths (see pp. 56, 57, 88), it is highly questionable whether the sensations result in anything more than a mere group of sensations, of sensations that may or may not occur simultaneously. It is questionable whether such an arrangement can give rise to a sense of existence any more than a single and separate sensation. Certain it is that it cannot give birth to that community of consciousness which constitutes a "sense of self." (See p. 113.)

What is the result of the assembling of the nuclear aggregations in the thalamus, of assembling all of the impacts which the organism is capable of receiving? Setting aside, for the time being, their rôle of way-stations in the pathways of transmission to the telencephalon, what rôle do they play in their relations with each other? In the first place, their close relation with each other must greatly facilitate responses along common paths; for instance, the close and primitive relations of the nuclear

aggregations for smell, taste and the viscera must greatly facilitate responses involving, first, the intake of food, and, secondly, the transmission of impulses along a common path to the digestive tract. Doubtless similar truths obtain in regard to the other nuclear aggregations and the transmission of impulses to other viscera, *e. g.*, to the circulatory apparatus or to the skeletal muscles, or to various glands and other structures of the body. Such responses would make their exit by way of the motor structures in the subthalamus and the striatum. However, this integration and coördination of responses is not the only outcome of the assembling of the sensory nuclear aggregations in the thalamus. A result of far greater magnitude ensues. New sensations, new feelings are born, due not to impacts received from without, but due to impacts transmitted from the various nuclear aggregations to each other. Under given conditions there is an "averaging" or "summation" of sensations. This may express itself negatively in a feeling of indifference or placidity, or it may express itself positively in a more or less pronounced feeling of comfort or sense of well-being. On the other

hand, it may express itself in a feeling of discomfort, of distress, of suffering, or of pain. Under given conditions these sensations may assume a very definite character; for instance, impacts transmitted from the digestive tract and from the body generally to the visceral and general somatic aggregations give rise to the sensations of hunger and thirst. An easy transition from these states results in a sensation of weakness and—certain factors being added—of fear. Under given conditions, as we shall see, the opposite emotion of courage and, it may be, of anger is experienced. It may indeed be safely claimed that the entire gamut of the sensations, feelings, and emotions have their seat in the thalamus, and this is true alike of a simple sensation such as a touch or sound, of simple emotions such as like or dislike, love or hate, and of our most refined and sublimated æsthetic experiences. To make the picture clear, however, and to place the facts in their proper perspective, an additional statement is now necessary.

It will be recalled that the thalamus is in close relation with the cerebral cortex; indeed, all of its nuclear aggregations save the olfac-

tory[1] are way stations in the pathways of transmission to the telencephalon, as has already been pointed out (see p. 67). However, and this is most important, the direction of transmission is not only to the cortex but through the cortico-thalamic fibers away from the cortex and back to the thalamus. True to its intercallary function the cortex transmits the impacts which it receives in many directions, and various combinations are formed among neurones receiving impacts from multiple and diverse sources. The exchange of impacts must be exceedingly complex and intricate, but in any event they must eventually resolve themselves into resultants of various kinds which—owing among other causes to the great number, the dynamic mass, of the neurones of the telencephalon—overflow and are now transmitted in the reverse direction from the cortex to the thalamus. Here they have all the effect of new impacts, but which now play upon the nuclear aggregations of the thalamus in the production of "feelings" which correspond to

[1] The olfactory lobes in mammalian forms have already established a direct connection with the telencephalon via the hippocampal gyrus. (See also p. 68, footnote.)

the interplay of neurones in the cortex. That the latter share in a measure the "feelings" is possible and probable, but their function is essentially synthetic, analytical, discriminative; the emotional reaction belongs to the thalamus. Synthesis results from the confluence of non-interfering impacts; analysis results from the fact that certain impacts having been admitted others are automatically excluded, or, are admitted separately as superimposed factors. In other words, if an impact which has been received is followed by a second in an opposite phase of motion, the second is neutralized; or, if it possesses a new quality, the latter is admitted as a motion superimposed. The separation of impacts means analysis. The combined action of synthesis and analysis is necessarily discrimination.

In the interplay between the cortex and the thalamus one fact stands out with striking prominence and that is the dominance of the cortex. This is evidenced in two ways. We have already seen that the train of transmission in the cortex possesses a relatively high dynamic level (see p. 122) and, therefore, whether new impacts transmitted by the thalamus find

entrance depends upon their intensity; it is purely a question of dynamics. However, up to a given point, a certain degree of resistance is offered to new impacts by the train of transmission—the field of consciousness (see p. 123). Its neurones are, so to speak, already "saturated" and the synaptic resistance is raised. On the other hand, the higher dynamic level results, as we have already seen, in an actual return flow to the thalamus. At the thalamus the same thing occurs. Its neurones are already highly charged with incoming streams; synaptic resistance becomes established and the activities of the neurones of the thalamus are lowered. In other words, an "inhibition" of the thalamus by the cortex obtains, and this inhibition is maintained to a greater or lesser degree in the normal condition of the organism.[1] In diseased states notable departures are observed (see p. 254).

The facts in regard to the telencephalon and the thalamus may be briefly restated as follows: Consciousness is the property of the neurones actually engaged in the train of transmission through the cortex. This is the "conscious

[1] It may be added that the explanation of inhibition here advanced is apparently applicable to inhibition generally.

field" (see pp. 105-108). Further, all consciousness is attended by "feeling," using this word generically to embrace the entire range of sensations: first, the special sensations received through the special receptors such as the sensations of touch, light, or sound; secondly, various basic feelings such as hunger, thirst, the sexual feelings; thirdly, various generalized feelings, the result of the interaction of the nuclear aggregations of the thalamus among each other, such as comfort, discomfort, well-being, and various special feelings such as fear and anger; lastly, more complex emotional states the results of the interaction of the cortex with the thalamus.

Regarding the dominance, that is, the inhibition, exercised by the cortex, there can be no question. This may show itself in regard to all of the feelings here outlined. As regards the special sensations, every one realizes that many purely physical impacts fail to gain entrance into the conscious field. A man busily engaged in writing does not hear the clock ticking in his room; he does not hear the clock strike; indeed, he may be spoken to and yet no cognition by him of the fact obtains. What is

true of sound is also true of other physical impressions of whatsoever character. It is also true of such basic feelings as hunger, thirst, pain, the sexual feeling. It is true likewise of the feelings of comfort, discomfort, well-being; true also of fear and anger; true also of the more complex emotions. Everything depends upon what is going on in the cortex, upon the interactions of its neurones, upon the dynamic level of the conscious field. But this dominance has its limitations. If sound impacts are sufficiently intense and insistent, they force their way in. This is true also of hunger, thirst, the sexual feeling; the soldier who does not feel the pain of a wound during the excitement of battle feels it later. The suppression of fear and anger likewise has its limitations, and this is true of all of our emotional experiences. It is, however, the dominance of the telencephalon which makes possible the coördinated adjustments favorable to the organism.

X

SYNTHESIS OF SPECIAL SENSE IMPRESSIONS

On a preceding page it has been pointed out that the function of the cortical neurones is essentially synthetic, analytical, discriminative (see p. 137). It should now be added that this triad of functions, which is subserved by the so-called association areas, results from the confluence of the transmissions of many and varied impacts. For instance, the ability to recognize, without the aid of vision, an object placed in the hand is due to the fact that the multiple tactual qualities of the object are transmitted by many and diverse pathways to the cortex where they finally reach an association area in the superior parietal lobule. First, there are the impacts resulting from simple contact; secondly, the impacts resulting from the weight of the object, *i. e.*, from the pressure of the object on the nerve terminations in the skin and from impacts derived from the proprioceptors in the muscles, bones, and joints, for the object is handled,

manipulated; the same receptors furnish, also, the impacts conveying hardness or softness. Receptors in the skin, together with muscle-bone and joint receptors, further send impacts conveying length, breadth, shape, etc. Smoothness, roughness, and other surface qualities are added and, finally, temperature. The confluence of the transmissions leads to a synthesis. If the object be a strange one never before examined, the transmissions leading to new combinations among the neurones, are separately taken up, *i. e.*, new pathways among the neurones era established, new synaptic resistances are overcome. It is only after this analysis has been completed that apperception is possible. Analysis, of course, necessitates discrimination and this merely means that given synaptic resistances are not overcome; certain pathways habitually opened up by similar objects remain closed.

This process of synthesis, analysis, and discrimination taking place in the association area of the superior parietal lobule is known as stereognosis. It occupies, of course, a part of the train of transmission, *i. e.*, of the conscious field. Various of the other association areas

offer analogous illustrations. One of the most interesting and important of these has to do with the function of hearing. In the mind of primitive man and, indeed, of his progenitors, there must have been formed an association of the sounds of nature with the objects or the phenomena giving rise to these sounds; just as man has learned to associate the tactual qualities of the objects of nature with the objects themselves. The evolution of sound recognition is therefore analogous to the evolution of the faculty of stereognosis. In stereognosis there is an association of tactual qualities, in sound recognition an association of acoustic qualities. In other words, to man's knowledge of the external world made up of the perception of tactual qualities, there is added, among other things, a knowledge of the external world made up of its qualities of sound. The primitive recognition of natural sounds, that is, the association of the sounds of nature with the phenomena giving rise to them, is a faculty which man no doubt shares in a degree with other animals. In man, however, the faculty of sound recognition has been enormously expanded. Based upon the faculty of the primi-

tive recognition of sounds he has evolved the exceedingly complex faculty of the comprehension of spoken speech. Here the associations demanded by the various vowel and consonant sounds, by pitch, by quality, by inflection, and by other factors, must be very complex and great in number. Further, the processes of association are rendered still more complex by the fact that in ordinary sound recognition there is the immediate association of the sound with the corresponding object in nature, while in the sound recognition of speech there is the recognition of definite and complex sounds usually associated not directly with the objects and occurrences of the external world but with the "conceptions," "memory pictures" of these objects and occurrences; that is, the complex sound impacts of speech in the course of their transmission through the cortex cause former associations to be revived (see pp. 114, 115). The area in which this special function of speech-sound association occurs is situated in the posterior portion of the superior temporal convolution of the left hemisphere. However, the train of association once started is not

limited to this region, but becomes more or less widely diffused. The train of transmission, now having assumed the form of speech-sound associations, continues in its course in this form. Thinking assumes the form of a train of speech-sound associations; that is, sound-words become the vehicle of thought.

The transmission of speech-sound associations necessarily extends to other association areas. Of special interest and importance are the areas of visual associations. In persons who have learned to read, speech-sound associations become closely linked with the printed or written characters or combinations of characters which represent the sound-words. So close does this association become that many persons habitually reinforce the sound-word, especially if it be a new word, by an examination of the printed or written word. Indeed, a few persons appear to do their thinking mainly with the latter; notably is this the case with those who suffer from impaired hearing.

XI

SPEECH

Speech was probably evolved very slowly. It is a perfectly tenable hypothesis that primeval man and, indeed, his ancestors, spontaneously uttered cries associated physiologically with fear, pain, anger, hunger, and with other basic feelings and emotions. Such spontaneous cries no doubt had a meaning for the "pack" or group as a whole. Ofttimes a cry constituted a warning of approaching danger or perhaps conveyed information of some other occurrence. The first attempt, however, to communicate definite information probably consisted of attempts to imitate sounds heard in nature. Thus, an imitation of a roar would give information of the presence of one of the dangerous carnivores; a howl would make known the presence of wolves; certain other sounds the presence of other dangers; later, given sounds would be associated with the presence of water, others with the proximity to food. Possibly in some such way as this

notions and ideas were in the beginning communicated; no doubt vaguely and very imperfectly at first. However, based upon such rudimentary beginnings, a progressive evolution both of spoken speech and speech comprehension is readily conceivable. The tendency in the young would be to imitate the articulate sounds made by the older individuals. In the course of time, the number of the sounds with a specific signification would increase and gradually the basic substratum of spoken speech would be established. The motor associations that are required are exceedingly complex; they include the innervations of the numerous muscles concerned in respiration, the complex muscles of the larynx, the muscles of the palate, of the tongue, of the buccal cavity, and of the lips. Most important of all is the coördination of the various structures involved, but complex as the associated and coördinated movements are, they early become automatic and subconscious. In other words, the neurones of the cortex and other structures concerned in the function early acquire relatively fixed relations.

Speech comprehension must of necessity antedate spoken speech. This is an unavoidable

hypothesis in the evolution of the speech faculty. As regards the acquisition of language by the child and of new languages by the adult, the facts admit of no reasonable doubt. The imitation of articulate sounds, especially by the adult acquiring a foreign language, is attended by a conscious effort. Sooner or later, both in the child and in the adult, the associations between the neurones concerned become potentially fixed. Head,[1] in an interesting paper on the subject of aphasia, expresses himself as follows: "The power to express ourselves in spoken words is acquired by voluntary effort, but ultimately becomes almost automatic. In the same way when learning to play the piano, the fingers are at first laid laboriously on each key, and a complicated apparatus is thrown into action, which sounds the note. Soon, with practice, the fingers move automatically and consciousness is occupied in reading the musical symbols on the printed page. Finally, with increased facility, even this becomes almost automatic; the expert musician scarcely sees the pages, for the nature of the musical phrase suggests to him the sequence of the accompanying

[1] Brain, Vol. XLVI, Part IV, Nov. 1923, p. 355.

harmonies." This parallelism beautifully illustrates the automatic character both of the reading and of the motor expression of the thing read.

The innervations concerned in spoken speech are, of course, cortical; *i.e.*, they arise in the motor centers of the operculum and in other portions of the motor area, and it is not improbable that a special association area exists in which these innervations are coördinated, namely, the third frontal convolution; though this conclusion has been questioned by Marie, by Souques, by Moutier, by the writer, and by others. However, the important point for our discussion is that these innervations are cortical. A second fact of great importance, in the opinion of the writer, now presents itself, and that is that the cortical innervations are not the sole innervations. All of the voluntary muscles are subject to a double innervation, one derived from the motor area of the cerebral cortex and the other from the primitive motor apparatus of the palæoencephalon, the striatum and its adjuncts.

We commonly, perhaps almost subconsciously, regard the striatum—in a large measure at

least—as a vestigial structure. The term "palæoencephalon," while appropriate and abundantly justified morphologically, is somewhat misleading, for the striatum is not wholly an ancient structure. The facts show that, like the cortex of the cerebrum, it has grown in size as we ascend in the scale of vertebrate morphology. It has evidently increased as the demand for associated movements of increasing complexity has increased. For example, the movements of the fish are exceedingly simple, and in keeping with this we find that the striatum of the fish is small and relatively insignificant. When we examine the brains of reptiles, we find that a new portion has made its appearance corresponding to the increased complexity of movements demanded by terrestrial life. To the older portion, which corresponds to the globus pallidus of higher forms, the term "palæostriatum" has come to be applied, while to the newer portion the term "neostriatum" has come to be applied. Again, the movements are more numerous and more complex in birds and most numerous and most complex in mammals, and in keeping with this the neostriatum has undergone a corresponding increase in size and com-

plexity. This increase in size and complexity finds its fullest expression in man; it is in man that the number and the complexity of movements reach their highest expression.

Projection fibers pass out of the striatum and come into relation with other motor structures in the subthalamic region, with the body of Luys, with the red nucleus, and with the substantia nigra. In the midbrain, pons, and medulla they come into relation with the motor nuclei of the various cranial nerves, and passing downward in the cord they come into relation with the motor cells in the anterior cornua, just as do the fibers coming from the motor area of the cortex, the pyramidal tract. Nature has furnished us with a number of pathological experiments which illustrate the relative rôles played by these two sources of innervation. For example, when a lesion occurs in the brain, such as a hemorrhage which cuts the pyramidal pathways across, a paralysis of the face, arm, and leg of one side of the body—the opposite side—results. The palsy, however, as soon as the condition is established, does not remain a flaccid, flail-like palsy, but the paralyzed parts become rigid. Although

paralyzed, the tone of the muscles is not lost; on the contrary, it is greatly increased. This apparently paradoxical result is due to the fact that the paralyzed muscles are now given over to the unrestrained innervation of the motor centers of the palæoencephalon, *i. e.*, of the striatum and its adjuncts. Under given conditions, the opposite occurs. Lesions of the striatum or other centers in which extrapyramidal pathways have their origin, are likewise attended by an increase of tone in the muscles involved. The rigidity presented by paralysis agitans or so often observed in the sequelæ of sleeping-sickness, is caused by the predominance of the now unrestrained innervation of the muscles by the motor area of the cortex.

According to the studies of Ramsay Hunt, the striatum has to do with automatic associated movements, with their control and coordination, and with the maintenance of muscle tone. As has already been pointed out (see p. 69), the responses of the striatum are definitely fixed. Impulses reach the striatum by way of the thalamo-striatal fibers. Such impulses may have their origin in impacts transmitted to the nuclear aggregations of the thalamus from

without and thence transmitted at once to the striatum, or they may be transmitted to the cortex and then back to the thalamus by way of the cortico-thalamic fibers and then, finally, to the striatum. There is much to justify the view that the latter course is the one commonly pursued; it is unlikely that the cortex so dominant in its influence would play no rôle in the thalamo-striatal interchange. In any event, it is very evident that the cortex is placed in intimate though indirect relations with the striatum.

An illustration of the basic rôle of the striatum in associated movements is furnished by the walk. When a foot is advanced in walking, the opposite arm is also advanced; that is, when the right foot is thrown forward, the left arm is also thrown forward, and with the left foot, the right arm. This automatic contralateral movement of the upper extremities is one of the most ancient of the automatic associations of land vertebrates and probably dates back to the time of the quadrupedal stage of man's ancestry. The interesting fact obtains that this association is lost when the striatum is destroyed. This is seen typically in paralysis agitans, in which the globus pallidus of the striatum, or the

pallido-rubrospinal tract, or, it may be, the subtantia nigra suffers from disease. Indeed, the loss or impairment of this association is one of the early diagnostic signs of paralysis agitans and of the conditions met with as sequelæ of sleeping-sickness, encephalitis lethargica. Concerning the rôle of the striatum and its adjuncts under these circumstances, there can be no question; and it does no violence to the facts in our possession to assume that the striatum plays a definite rôle in all fixed associated movements. For example, swimming, though acquired with conscious effort, soon becomes automatic. It is exceedingly probable that the movements become a part of the function of the striatum; it would certainly be impossible for a man with a lesion of the striatum to swim, no matter how capable he had been in this respect previously.

We must bear in mind that the double innervation here described is present in all voluntary muscles. Not a single movement can be made without both innervations being called into play. They act, of course, synchronously. The cortex takes the lead, the striatum acts in unison, and, if the movements be frequently repeated, fixed as-

sociations are formed in the striatum. This appears to be true of the associations concerned in playing a musical instrument and also true of those complex associations concerned in spoken speech. Upon this basis only can be explained the speech disturbances, the anarthrias, met with in the lesions of the striatum in cases of pseudobulbar palsy, or in those cases of "motor aphasia" or "anarthria" in which lesion of the striatum has been found with integrity of the third frontal convolution. It was Marie who originally made this observation and insistently called attention to it.

Dealing with fixed associations, the striatum clearly plays no rôle in consciousness. Consciousness is, as we have seen, limited to the train of transmission through the cortex; it is featured by "feelings" in proportion as these are transmitted from the thalamus and in proportion as they are admitted by the neurones concerned in the train of consciousness (see pp. 139, 140). The striatum plays no part. This is likewise true of the cerebellum. The latter is the seat of fixed neurone combinations upon which depends the coöperation of the muscles or, rather, groups of muscles, concerned in the

various movements of the trunk and limbs. Every exertion, such as standing, every movement, such as walking, every action of an extremity or of any portion of the body, such as the organs concerned in speech, require the coöperative action—the synergic action, as it is termed technically—of an immense number of motor innervations. This synergic action, the detailed consideration of which would take us too far afield, makes possible harmonious, regulated, coördinated movements. If this coördination of motor innervations be impaired by disease of the cerebellum, standing is maintained with difficulty, the body sways excessively because of loss of balance, loss of equilibrium, while walking becomes disordered, ataxic, and staggering. The extremities are moved irregularly, thrown about excessively, jerkily, awkwardly. A simple illustration will make the action of the cerebellum clear. Let us take the facts presented by the simple extension of an extremity, *e. g.*, an arm, the various segments of which are flexed upon one another. The muscles concerned both in flexion and extension are, through the influence of the cerebellum, constantly maintained in a con-

dition of tone, *i. e.*, in a state of moderate contraction; like the strings of a violin, both flexors and extensors are attuned to a certain pitch. When, now, impulses are sent down from the motor area of the cortex to the extensor muscles, these muscles contract and the arm is extended, but the flexor muscles do not suddenly relax; they yield gradually like a band of tense rubber, and the extension of the limb is accomplished smoothly, evenly, not jerkily and suddenly. This applies to the extension, the unfolding of the various segments of the arm in their entirety: the extension of the upper arm upon the shoulder, the extension of the forearm upon the arm, of the wrist upon the forearm, of the hand upon the wrist, and of the fingers upon the hand. These movements occur in an associated sequence. The separate and incoordinate extension of the segments of a limb is a well-known symptom of cerebellar disease.

The mystery of the cerebellum largely disappears when we reflect that it is the recipient of an immense number of impacts from the proprioceptors in the muscles, tendons and joints of the trunk and limbs, and that it has intimate though indirect relations with

the voluntary muscles through the red nucleus. The response which it gives to the impacts consists in the production of muscle tone. This muscle tone is in direct relation with, varies with, and is proportioned to, the impacts received. The point of importance in our present discussion is that the neurone associations being fixed, as already pointed out (see p. 64), neither the incoming or outgoing impacts play any rôle in consciousness. This is equally true of the equilibratory mechanism constituted by the semicircular canals, Deiter's nucleus, and the cerebellar connections of the latter. It is only when disturbed by disease or other special incident that impacts from these sources force their way into the train of transmission in the cerebral cortex.

XII

GENERAL SYNTHETIC FUNCTION OF THE VARIOUS RECEPTIVE AREAS OF THE TELENCEPHALON

The general truths illustrated by the above considerations of the association areas of tactual impressions and of sound impressions are clearly applicable to the other association areas as well. For instance, in the visual association area in the occipital lobe—which immediately adjoins that concerned in the actual reception of the visual impacts transmitted from the thalamus—the various qualities of the object seen are associated; its form, the character of its surface or other parts presented, its brightness, dimness, its color, relative dimensions, its nearness or remoteness, its relations in perspective to other bodies in the visual field, besides many other qualities. The areas for smell and taste discharge analogous functions. This is probably also true of areas for the visceral and bodily sensations. Their rôle has already been in large part considered. A final fact now re-

mains to be stated. The action of a given association area resolves itself into a resultant. For instance, the hand is thrust into the pocket which contains various objects, *e. g.*, some coins, a pocket-knife, a key. As a result of the action of the tactual association area in the parietal lobe, stereognostic perception occurs and the key is isolated, selected, and drawn from the pocket. The key being seen, the visual association area now in like manner combines the various visual qualities of the key. Again, from a bowl containing fruit, an apple is selected. Its tactual qualities are at once combined in the tactual association area; its color and form in the visual association area; the sounds that are made when a piece is bitten off and masticated, in the auditory association area; its odors and flavors in the corresponding association areas; and the visceral sensations arising from the passage of the food through the œsophagus into the stomach—satisfaction, well-being, contentment—also in their appropriate areas. The point of importance for us is that it is the *resultants* of the action of the various association areas which enter the train of transmission, the field of consciousness. They enter,

some of them simultaneously, others in sequence; all in varying degree. The train of transmission—thought—deals not with isolated impacts, but with these resultants; the latter, associated and combined, flow along, as it were, in final common paths. It is in this way that "concrete" thinking is done.

There is another area of the brain, however, in which synthesis, analysis, and discrimination are carried to a far higher degree. This area is apparently situated in the frontal lobes. Here synthesis, analysis, and discrimination are carried to such an extent that these processes result in the "averaging" of concrete conceptions. These are now reduced to mere symbols and concrete thinking gives way to "abstract" thinking. Immediately in front of the motor area lies an area which probably has to do with those associated or coördinated transmissions to the motor convolutions which result in emissive discharges. Still farther in advance of this area, however, is another, an area involving the extremity of the frontal lobes, and it is here that in all probability abstract thinking is done. It is an interesting fact also that there is a free intercommunication between the frontal lobes

and the thalamus. This insures to the neurones concerned in abstract thinking all the ranges of "feeling." The latter are, as we have seen, admitted to the train of transmission in varying degree and in accordance with definite principles (see pp. 137–139). They may at one time be admitted freely and at another be icily excluded.

XIII

FACTORS WHICH INFLUENCE THE FUNCTIONS OF THE NEURONE

LET us now turn our attention to another aspect of the subject. Other factors than the reception and transmission of impacts influence the behavior of the neurone. Among these are the nutritional and other agencies to which it is subject. The body of the neurone lies in a lymph-space. As in the case of all the other structures of the body, its relations to the blood-stream are indirect; nutrition is effected only through the lymph in which it is immersed. This is, of course, equally true of the dendrites, axones, and synapses; for the very capillaries which supply these structures themselves lie in lymph-spaces. Contrary to the error frequently maintained, the lymph-space in which the body of the neurone lies, the periganglionic lymph-space, has no communication with the cavities containing the cerebrospinal fluid. The latter, as the writer has definitely shown,[1] is

[1] Dercum, Archives of Neurology and Psychiatry, March, 1920, Vol. III, pp. 230–251.

virtually a "common salt solution" which has the purely physical function of acting as a hydrostatic support to the soft, mechanically vulnerable brain and cord. It has nothing to do with the nutrition of the nervous substance. The nutrition of the latter depends definitely and solely upon its vascular supply.

Again, the maintenance of the function of the nerve cell means the maintenance of its metabolism. The reception and transmission of impacts is, as we have seen (see pp. 93–99), accompanied by an electrochemical change. This change is one of reduction. Of necessity it is attended by a consumption of substance, just as in the instance of the zinc plate of a galvanic battery. Hodge and others years ago demonstrated a reduction in the volume of nerve-cells as a result of the excessive exercise of their function. The loss is, of course, replaced by a corresponding up-building. The blood-plasma transfers the necessary materials through the walls of the capillaries into the periganglionic lymph-spaces; here they have ready access to the cell bodies. Under physiological conditions, the catabolism and anabolism of the nerve cell go hand in hand; in other words, the materials

for the electrochemical changes are supplied as fast as they are consumed. It is for this reason doubtless that normally nerve-cells show no appreciable change as a result of their functional activity.

The nerve-cells not only receive from the blood-plasma the material necessary for their reconstruction, but are also exposed to other substances which profoundly influence their activity. Among these are especially the substances elaborated by the glands of internal secretion, the hormones; and to these we will for a brief period give our attention.

All of the glands of internal secretion have to do with chemical changes. Some of them exercise a more or less general and widely distributed influence on the metabolism and nutrition of the organism; others are more or less special in their function, such as the sex glands, the cortex of the adrenals, and perhaps the pineal. Those whose action is more general resolve themselves into two groups, whose effects on metabolism are diametrically opposed. The first group consists of the thyroid, the pituitary, and the chromaffin system; the second, of the thy-

mus, the parathyroid, and the pancreas.[1] These two groups stand in physiological antagonism with each other. The thyroid, the pituitary, and the chromaffin system form a synergic group; all of them increase metabolism, all of them promote the release of energy. The thymus, the parathyroids, and the pancreas form another synergic group. The pancreas and, in fact, all of the glands of the alimentary tract together with its adnexa are concerned with the processes of digestion and assimilation, *i. e.*, with the storing up of energy. The thymus and the parathyroids are both in synergic relation with the pancreas and must, therefore, be included in this group. The close relations which exist between the chromaffin system and the sympathetic nervous system proper justifies the application of the term "sympathetic" to the first group, while the vagotonic rôle of the thymus justifies the application of the term "autonomic group" to the second.[2] The first is catabolic, the second anabolic, in its action.

The readiness of response of the neurone is

[1] Dercum, Biology of the Internal Secretions, W. B. Saunders Co., 1924.

[2] Dercum, loc. cit., pp. 59, 65, 140.

at times heightened, at times lessened, in accordance with the relative activities of the two groups. Under normal conditions fluctuations occur within a comparatively limited range; for instance, during physical activity the sympathetic group—the chromaffin, thyroid, pituitary group—is dominant. An increase of function is noted in various organs; the muscles are intoned, the heart's action is accelerated and strengthened, the respirations are increased in frequency, the pupils are dilated and admit more light. At the same time the nervous responses are increased both in number and in volume; the organism is more alert and reacts more quickly. On the other hand, during periods of relative quiet, as, for instance, after the taking of food, it is the autonomic group which now asserts itself. Digestion and assimilation are now dominant. The muscles are relaxed, the heart and respiration slowed. Nervous rest and quiet, perhaps torpor or sleep, ensue.

The question as to the mode of action of the hormones upon the nervous system is exceedingly interesting. It is certain that the thyroid secretion—or rather its active principle, thy-

roxin—increases the intensiveness of the chemical processes going on in the body. The carbohydrates and fats reveal an increased metamorphosis. The consumption of oxygen and the output of carbon dioxide are increased, while the increase in the disintegration of the proteins leads to an increased output of nitrogen. The heightened activity of the neurones may be merely the outcome of the general increase of metabolism. However, the very definite nervous symptoms observed in pathological states in which the thyroid secretion is in excess—extreme restlessness, sleeplessness, active delirium—point to a direct action of the thyroxin upon the neurone. It acts probably both upon the cell body by stimulating and perhaps modifying its metabolism, but, also, in all probability upon the synapses; the action in the latter instance being to lessen synaptic resistance. Possibly and very probably the action of the hormones of the chromaffin system and of the pituitary is both direct and indirect. Many of the nervous symptoms, however, observed both in adrenal and pituitary disease suggest a direct action; regarding the results of the action of the group as a whole there can

be no question. The action of the autonomic group is likewise probably both direct and indirect. Direct action upon the neurones is suggested by the lessening and slowing of the responses; as though the metabolism of the cell body were diminished and the synaptic resistance increased.

The fluctuations which occur between the activities of the two groups play an important rôle in the train of transmission through the cortex. At the time of the dominance of the sympathetic—the catabolic group—both the speed and the volume of the train of transmission are increased; in other words, the individual thinks more actively and the field of his consciousness is enlarged. The reverse obtains when the autonomic group—the anabolic group—is dominant; thought is less active and the field of consciousness is contracted. In pathological conditions the fluctuations may be greatly exaggerated, and under such circumstances transmission is profoundly influenced *e. g.*, in mania, in which it is greatly increased in speed and volume, and in melancholia, in which it is very greatly retarded and reduced (see pp. 253, 255).

Finally, the internal secretions play an additional and most important rôle in their action upon the nuclear aggregations in the thalamus. In part this action is individual and specific, in part it is general and collective. It is exceedingly probable that in this way are excited the primitive sensations of hunger, thirst, fear and anger, and also the generalized feelings of comfort, contentment, and well-being; or of discomfort and distress. These thalamic sensations, as we have already seen (see pp. 133–136), serve as the basis for the more complex emotional states. Again, the hormone of the sex glands by its action on the corresponding nuclear aggregation in the thalamus—in the floor of the hypothalamic portion of the palæothalamus—excites the sex-feeling, the sexual want. All of these sensations, or rather the impacts into which they resolve themselves, find entrance under given conditions into the train of transmission in the cortex.

XIV

INSTINCTS. TROPISMS

The close relation which obtains between instincts and the internal secretions demands a further consideration both of the instincts and of the problem of the internal secretions. The latter we must remember are included in the general problem of the metabolism of the organism.

On page 115 it is suggested that some of the instincts and race memories have their origin in neurone combinations of such frequent recurrence in the ancestry that they have acquired all the potentialities of inherited structure, and again on page, 117 that some instincts are inherited modes of reaction to the environment that had their origin in responses which early in the phylogeny of the race were adjustable, and which, owing to constant repetition, have become fixed and relegated to the subconscious field. Before turning our attention to the instincts of mammals, let us turn our

attention to instinct as manifested by some of the other forms of life. At once we are impressed by a remarkable series of facts to which the name "tropism" has been given. The term, derived from the Greek, τροπή, turning, has its origin in the tendency observed both in many plants and animals to turn toward the light, and the phenomenon itself has received the name of "heliotropism." Several other forms or causes of "turning" have been recognized, but let us for the moment confine our attention to heliotropism. The purely physical character as revealed by the turning of leaves to the light, by the growth of vines toward the light, by the turning of the disc of the sea-anemone to the light, must, I think, be freely admitted. Similar is it with the remarkable behavior of the moth to the flame or the flight of birds toward light, as witness the large number of the latter who annually lose their lives by flying at the beacon of the Goddess of Liberty in New York harbor. The chemical and physical action of light upon plants and upon lowly organized forms of animal life such as the sea-anemone, do not here demand our consideration. As regards the reaction of more

complex forms of life as revealed by insects, the facts have been most elaborately studied, and they have shown that the positions assumed or the movements resulting are directly related to the direction from which the light is received and to the intensity and duration of the illumination.[1] From what we have learned (see pp. 94, 96) concerning the impacts of light upon the retina and the resulting electrical streams, it can readily be understood that the latter, acting as they must upon the definitely arranged neurone structure of the animal, must produce definite or specific results both as regards the positions assumed or the motions adopted. The story, however, does not end here, for under given conditions remarkable phenomena appear which prove that the metabolism of the animal, as revealed by its internal secretions, has been profoundly affected. For instance, "In ants, the winged males and females become intensely positively heliotropic at the time of mating. Copulation occurs in the air in the so-called nuptial flight. At a certain time—in the writer's observation toward sunset, when the sky is illuminated at

[1] Jacques Loeb, loc. cit., pp. 47–111.

the horizon only—the whole swarm of males and females leave the nest and fly in the direction of the glow. The wedding flight is a heliotropic phenomenon presumably due to substances produced in the body during this period." [1] The wedding flight of other insects, *e. g.*, of bees and wasps, furnish similar instances. They are beautiful illustrations of the reactions of complex organisms to an incident force of the environment; reactions to which the word "instinctive" may be properly applied. The word instinctive now acquires a very definite and special significance.

That the organism should react automatically to other forces and conditions of the environment becomes readily comprehensible. For instance, it reacts in this way to the influence of gravity, to contact with foreign bodies, to chemical impressions, and, in the laboratory, to the play of the galvanic current. The response to the influence of gravity has been termed "geotropism," that to contact, "stereotropism," that to chemical substances, "chemotropism," and so on. From what has been said earlier in this volume, it is obviously unnecessary to consider these

[1] Jacques Loeb, loc. cit., p. 158.

reactions in detail. One fact, however, it is important to bear in mind, and that is that into the automatic response of the organism the different influences of the environment may enter in a varying degree. Loeb showed, for example, that the reactions of organisms to light could be greatly influenced by chemical reagents; thus certain fresh water crustaceans normally indifferent to light can be made strongly positively or negatively heliotropic by various acids and alcohols; and it made no difference whether the substances, such as acids, were formed in the tissues of the animals or introduced from without. Clearly their action is indistinguishable from that of hormones normally circulating in the blood. Loeb calls attention to the fact that Lillie's observations revealed that in the blood of the male cattle embryo substances circulate which inhibit the development of the secondary sexual characters of the female embryo, and that Steinach's experiments have shown that when the interstitial tissue of the sexual gland of one sex is introduced into the castrated organism of the opposite sex, it may impart to the latter the sexual instincts of the former. The conclusion is inevitable that the

reactions of an organism are profoundly influenced by its hormones.

Stereotropism and its relations to hormones is illustrated in the mating of fishes. During the mating season the distended structure containing the male elements is pressed by the male against the body of the female near the corresponding aperture in the body of the latter; who responds by pressure. As a result ova and spermatozoids are commingled. A high degree of specificity is attached to the act, the mating occurring always between individuals of the same species. The explanation of this specificity is probably to be sought in odor, which plays so important a rôle in the life of the fish (see p. 59). This is the more probable as we know that sexual maturation in many animals is attended by odors not present at other times. The odor is in all likelihood reinforced by vision, and doubtless and especially by the contact of mating. However, this specificity is not absolute, for, according to Loeb, females who are kept isolated from the male, will during the mating season discharge their ova automatically every time they come into contact with the glass walls of the aquarium. Loeb interprets

the act of mating as due to the hormones developed during the mating season. In the intervals no such reactions are noted; a condition of stereotropic indifference is established. However, in some of the females of other animals, a decided reversal of reaction to incident factors of the environment occurs, and new properties may be manifested. For instance, the female ant after the sexual flight loses her heliotropism and now becomes stereotropic, seeking dark places and contact with solid bodies.[1]

The reactions to the environment of organisms with fixed neurone structure coupled with the reactions of this same neurone structure to the hormones—the products of the metabolism of the animal—serve as a ready explanation of the conduct which we in ordinary language characterize as instinctive. This explanation must apply equally to instincts that are highly complex as well as to instincts that are relatively simple. Exceedingly complex instinctive actions are especially presented by insects. Thus, the solitary wasp after finding or digging a suitable hole, provides her prospective offspring with food in the form of a captured

[1] Jacques Loeb, loc. cit., p. 158.

caterpillar, deposits her eggs upon the latter, closes the nest, and then flies away, never returning. She never sees her offspring. Has she a knowledge of the meaning of what she has done? or is the entire procedure fixed, automatic, subconscious? Sometimes errors of observation give to instinctive actions a complexity which they do not really possess; for instance, the solitary wasp Ammophila was believed to plunge its sting exactly into the nerve ganglia of its victim and thus to paralyze but not to kill its victim. Its larva would thus be supplied with living food. However, it has been shown that what the wasp really does is to insert her sting between the segments of the caterpillar where the outer covering of the latter is most readily penetrated; that the ganglia are not necessarily reached; that the wasp sometimes repeats the stinging operation a number of times; that the caterpillar is sometimes not merely paralyzed but actually killed; and, finally, that this makes no difference to the larva of the wasp. Another instance of exceedingly complex and very remarkable behavior is furnished by the Yucca moth, Pronuba yuccasella. This moth collects the pollen

from one flower, deposits her eggs among the ovules of another flower, and then inserts the pollen which she has collected into the pistil of this second flower. The larvæ now feed upon the yucca seeds, burrow through, drop to the ground, pass into the chrysalis stage, and remain in this stage until the yucca plant flowers again; when the adult moth makes its appearance and repeats the triple act of collecting pollen, depositing its ova, and inserting the pollen into the stigma of the pistil of the depository. The life cycle of the yucca moth is thus reduced to the narrowest possible limits, but the extreme specialization of its instinctive actions secures the perpetuation of the species. A large number of complex behaviors is furnished, also, by the insect communities, such as bees, wasps, and ants. These, however, we will not pause to consider.

In attempting to interpret the complex instincts of insects several important facts should be borne in mind. To begin, there is the very remarkable division of the development of the insect into two stages. The ovum contains an amount of nutrient material utterly inadequate for the development of the adult individual;

therefore, just as soon as the embryo has reached a stage which in its essentials consists of a simple series of segments provided with a digestive apparatus, it makes its appearance in the external world, and the entire business of its existence then consists in the taking in of food. Just as soon again as it has become surfeited with food, turgid with energy, it once more becomes quiescent, and the development of the individual is now completed.

In this process of completion—and this is very important—there are condensed into a few weeks changes, stages of evolution, which in the ancestors of insects doubtless required vast ages of time. The facts justify the inference that the tracheæ gradually gave rise to wings, the œsophageal collar to the large œsophageal ganglion, the imperfect eyes to the marvellously complicated apparatus of the present adult forms, while the various segments gave rise to complicated limbs, to prehensile organs, to mandibles, and to other structures. In the chrysalis all this has been condensed, abbreviated; short cuts have doubtless been here and there established and here and there intermediate stages omitted.

It is fair to assume, further, that in these processes of evolution in the ancestral forms, the nervous system also underwent corresponding and important changes. Simple and primitive arrangements of the neurones were succeeded by others more and more complex, each stage corresponding to new adaptations necessitated by the environment. In the chrysalis this process has also been condensed and here and there intermediate stages omitted. In the adult insect of today—the imago—we find, therefore, fixed neurone combinations, many of them of great complexity. These under appropriate stimuli lead to various forms of behavior, some of them more or less complicated.

In how far do these instinctive reactions enter the field of consciousness? Being fixed they are doubtless in a large measure subconscious (see p. 105), but are they wholly so? Observations show that a conscious field is occasionally, at least, touched upon or aroused. Loeb, for instance, states that "An Ammophila had made a hole in a flower bed and left the flower bed flying. A little later I saw an Ammophila running on the sidewalk of the street in front of the garden, dragging a caterpillar which it

held in its mouth. The weight of the caterpillar prevented the wasp from flying. The garden was higher than the sidewalk and separated from it by a stone wall. The wasp repeatedly made an attempt to climb upon the stone wall, but kept falling down. Suspecting that it might have a hole prepared in the garden, I was curious to see whether and how it would find the hole. It followed the wall until it reached the neighboring yard, which had no wall. It now left the street and crawled into this yard, dragging the caterpillar along. Then crawling through the fence which separated the two yards, it dropped the caterpillar near the foot of a tree, and flew away. After a short zigzag flight it alighted on a flower bed in which I noticed two small holes. It soon left the bed and flew back to the tree, not in a straight line, but in three stages, stopping twice on its way. At the third stop it landed at the place where the caterpillar lay. The caterpillar was then dragged to the hole, pulled into it, and the hole was covered with tiny stones in the usual way."[1] Here evidently the wasp met with difficulties for which the inherited fixed neurones aggrega-

[1] Jacques Loeb, loc. cit., p. 170.

tions did not provide, so that the animal was obliged to make new and original adjustments; in other words, "instinct" was here supplemented by a conscious process in which inference, deduction, and an original course of action played essential and conscious rôles. Again, Mc Dougall gives the following instance: "Wasps of another species prey on spiders and always draw their prey into the burrow by walking backward, with the spider held in the jaws. One such wasp, holding her spider by the ventral surface, was prevented from drawing it into her burrow by the resistance of the spider's spreading legs. She tugged hard and long, but in vain. At last she released the spider, took a new grip of it, this time by the dorsal surface, and then backed easily into her hole, the legs folding up like an umbrella." Did the wasp here stop to "think"? What other interpretation is it possible to place upon her action? McDougall[1] gives many instances of the intelligence of the wasp, such as her ability to find her nest, an ability which is evidently due to a knowledge which she has acquired of the neighborhood, its features, its landmarks, so to speak.

[1]McDougall, An Outline of Psychology, Methuen & Co., London, p. 90.

Finally, another specific instance may be added: the Ammophila has even been observed in closing her nest to use a small pebble with which to hammer down the earth, to tampon the opening. She has actually been observed to use a tool. Why should she be denied a measure of "mind"? She may not know—probably does not stop, or cannot stop to think—why she digs the hole, why she seeks the caterpillar, why she drags the latter into the hole, why she deposits her eggs upon it, or why she closes the opening of the hole. All of this may be tied up in the neurone combinations of the one-time conscious adjustments of a long forgotten past; but conscious action she may and clearly does at times add to—does at times superimpose upon—her purely instinctive actions.

The birth of some of the instinctive actions can be traced, or at least their origin suggested, by the tropisms of Loeb.[1] For example, Loeb points out that the underlying mechanism of the instinct of many insects to lay their eggs on material which will serve as a nutritive medium for the offspring, is the result of a positive chemotropism of the mother insect for

[1] Jacques Loeb, loc. cit., p. 160.

the type of substance serving her as food, and that "when the intensity of these volatile substances is very high, *i. e.*, when the insect is on the material, the egg-laying mechanism of the fly is automatically set in motion. Thus the common housefly will deposit its eggs on decaying meat, but not on fat; but it will also deposit it on objects smeared over with asafœtida, on which the larvæ cannot live. Aseptic banana flies will lay their eggs on sterile banana, although the banana is only an adequate food for the larvæ when yeast grows on it. It seems that the female insect lays her eggs on material for which she is positively chemotropic, and this is generally material which she also eats. The fact that such material serves as food for the coming generations is an accident. Considered in this way, the mystic aspect of the instinctive care of insects for the future generation is replaced by the simple mechanistic conception of a tropistic reaction. In this case natural selection plays a rôle, since species whose females would too frequently lay their eggs on material on which the larvæ cannot thrive would be liable to die out." Doubtless analogous reactions lie at the basis of other relatively simple

acts. However, the theory of tropisms will of itself hardly suffice to account for the establishment of a long series of complicated and apparently logically related procedures, such as observed in the solitary wasp or in the insect communities, bees and ants. Conscious reactions in ancestral forms, conscious adjustments and readjustments in which the basic tropisms necessarily played a genetic and controlling rôle, seems to the writer to be the most logical explanation of the actions of some of the insects of the present day. Procedures at one time the outcome of such conscious adjustments sooner or later became fixed and then entered the "unconscious field" (see p. 119). For the most part, the insects of the present day present a nervous make-up which is truly crystalline in its fixation, and yet now and then, as in the incidents cited above, the presence in a degree in some insects of adjustable responses is observed. This, I believe, let me repeat, is to be regarded as the persistence of a "conscious" reaction which in bygone ages played a larger and much more important rôle in the ancestral forms.

The consideration of instincts as exhibited by

insects enables us to understand somewhat more readily those of vertebrates. We have already called attention in the case of animals provided with a telencephalon, to the striking difference between the responses of this structure and the responses of the segmental brain, the palæoencephalon. The responses of the latter are fixed and invariable, while the responses of the former are those of adjustment and change. It is therefore in the palæoencephalon that those fixed reactions which we call instinctive have their seat. We have already considered the rôle of the thalamus in the reception and play of the entering impacts and the rôle of the striatum and other motor structures of the palæoencephalon in the emission and control of impulses. The facts as revealed in the preceding pages leave no doubt as to the function of this mechanism; and, finally—let us repeat it once more—that this mechanism is fixed.

In fishes in whom a telencephalon is lacking, such adjustable responses as occur must necessarily be made by the segmental brain. These adjustable responses are very few and most of them very doubtful. They include the return to the same feeding grounds, the possible avoid-

ance in a small degree of danger, and, in a few instances, of the protection of the spawn. It is probable that we are here really dealing with basic tropisms and little else. In amphibians, the rudimentary telencephalon appears to be the seat of a few associations. As in fishes the life is almost wholly that of the palæoencephalon and spinal cord, and this is also true of reptiles. In birds the telencephalon—the pallium—has increased but little over that of reptiles, and inasmuch as birds are capable—though in a very limited measure—of forming adjustable responses (see p. 103), these must be formed by the palæoencephalon. It is probable that the early palæoencephalon, the palæoencephalon of ancestral forms, was likewise capable of adjustable responses and to an even greater extent, but in the course of time these responses became more and more fixed. Founded in their very origins upon the basic tropisms, they gave rise to the complicated instincts of the birds of the present day.

In a sense birds represent a line of organisms so highly specialized and differentiated that in them evolution has almost run its course. Not only have their neural reactions become fixed,

but so has their very structure. In this respect they present an analogy to the insects, though in the latter the process of "crystallization" appears to have reached the "nth" degree. I believe that very few biologists will venture to prophesy any radical departure in the further evolution of either birds or insects. Our world is a very old world; balances have been struck; relations between highly specialized organisms and their environment have become narrow and permit of but little interplay. Fresh adaptation may take place in such forms, but these adaptations will in all likelihood be relatively limited. Finally, we should bear in mind that in dealing with the instinctive actions of such forms as insects, we are dealing with end-results, and this is true in a large measure also of birds. Mating, nest building, brooding, and the feeding of the young are to be explained on the basis of very ancient tropisms and almost equally ancient adaptable responses. The migration of birds appears to depend upon food tropisms, upon the tropistic relations of given birds to given currents known to be constant in the upper regions of the atmosphere, and possibly upon other facts as well. The

homing of the carrier pigeon, for instance, is probably made up of environmental recognition and possibly also of "wireless" or other perceptions not experienced by ourselves. In fishes food and sex tropisms combined with currents in oceans and streams appear to be the effective agents. In insects, food tropisms, sex tropisms, environmental recognition, no doubt play a varying rôle. Is it not conceivable, however, that in certain forms, *e. g.*, butterflies, the antennæ serve the purpose of "wireless" receptors? serve the purpose of wireless transmission from mate to mate?

When we approach mammals we note, of course, instincts founded—as in other vertebrates—upon basic tropisms, some of them very ancient. For instance, such a basic tropism is found in the close physical association of mother and offspring, an association which may have had its origin in so simple a factor as the warmth of the body of the mother. Further, this physical association finds an especial expression in a clinging contact of the mouth of the offspring to the body of the mother. This apparently had its beginnings in the days of the monotremes, and in later days led to the definite development,

from primitive cutaneous sebaceous structures to highly differentiated glands yielding nourishment to the offspring. A specific stereotropism was early established and one that is so ancient that it is not surprising that one of the first instinctive acts of the newborn mammal should be that of suckling. The stereotropic reaction of the offspring is not absolutely specific, for the newborn mammal for a time goes through the act of sucking with almost any object placed in its mouth. Another stereotropic reaction is observed in the developing infant. For a long time objects which it happens to grasp are carried to the mouth irrespective of their character. It would almost seem that along with the hands the mouth aids materially in the development of the stereognostic sense.

The intimate stereotropism that exists between offspring and mother leads to very interesting results. It is not strange that the foal follows its dam or that the human infant toddles after its mother. In the human infant the stereotropism eventuates in far more, namely, in the love of the child for the mother, an emotion which in the higher races of mankind reaches a very high degree of expression.

The instinctive standing and walking of the newborn foal and the instinctive efforts made by the human infant at locomotion—rolling, creeping, walking, climbing—are all of them the outcome of the fixed reactions of the palæoencephalon (see p. 152). This is equally true of the basic feelings of hunger and fear which have their seat in the palæothalamus, and of the reactions which these feelings entail. The instinct which prompts the young animal to seek safety in hiding—a form of stereotropism—or which prompts it to seek safety in flight, finds a similar explanation; namely, in the reactions of the nuclear aggregations of the thalamus and of the motor structures of the palæoencephalon. When the animal is more mature, the same factors lead it to active resistance, to struggle and attack. An emotional phase which is the opposite to that of fear is now experienced, namely, anger, and this in turn reinforces the outpour of energy in the combat. Fear and cowardice, anger and courage are all related states and require no elaboration. One fact now becomes evident and that is the domination, the inhibition, of these instinctive reactions by the telencephalon, an inhibition which reaches its highest

expression in the human cortex (see pp. 137, 139, 140).

When the animal becomes mature, the instinct of sex becomes manifest. Sex feeling, sex want, asserts itself. The interplay of the sex hormones and the corresponding nuclear aggregation in the palæothalamus have already been considered, and the subsequent approach and physical relation of the two sexes in mammals does not differ in its essence from that observed in other vertebrate forms, and which we have already considered in dealing with the sex-stereotropism of fishes (see p. 176). In the human animal, again, it is subject to the domination and control of the cortex. It is also in man the well-spring of the emotion of love between the sexes, which, again, finds its highest expression in the most highly organized races.

When the sexual relation eventuates in the birth of a child, the mother reacts actively to the stereotropism of the infant. Mother care, mother protection, and finally mother love, which usually persists throughout the lifetime of the individual, are established. Here again, of course, the cortex plays a rôle. Deficiencies, subnormalities, are usually featured by neglect,

indifference, or, it may be, abandonment. The normal woman, however, responds to the emotion even to the extent of extreme self-sacrifice.

The relations of the father to the child and of the child to the father have, of course, a different origin. Primitive man, as in the case of other animals, at times fought for the possession of the female; sometimes the latter was stolen from a neighboring group, a neighboring tribe, but, however acquired, she became an object of possession. Possession meant, of course, care, defense, protection. Necessarily this included the offspring. The care of the latter, however, extended at first over a relatively short period of time, and the young were compelled to take, or spontaneously took, part in the struggle for existence at an early age; as they still do among the primitive peoples of our own day. However, the sense of responsibility on the part of the father—in fact, of both parents—gradually grew until, as at present among civilized peoples, this care extends up to or into the adult period.

As regards the father, another and powerful influence is at work. The mother transmits her traits not only to her daughters, but to her

sons, and among these is her basic instinct of love for the offspring. The affection of the father for the latter is therefore spontaneous. Further, this emotion was in time reinforced by a sense of possession; which, as the family grew, led to a feeling of solidarity, of added strength and security. These factors naturally reacted upon the child. The affection of the child for the father is, of course, of much later birth than that for the mother. However, it makes its appearance in childhood and, other things equal, grows with the emotional and mental development of the child.

XV

PHYSICAL PRINCIPLES UNDERLYING PLEASURE AND PAIN

Enough has perhaps been said in the preceding pages to indicate the nature of instincts. Let us now pass to another aspect of the subject. The fundamental physical principles which underlie such elementary phenomena as pleasure and pain now demand our consideration. An impact received by an exteroceptor and gaining admission to the train of consciousness may give birth to a specific sensation, say of sound; this sensation may be unattended by any other quality. On the other hand, the sensation may be definitely pleasurable, or, again, it may be definitely painful. Further, certain sequences of sound and certain combinations of sound give us the pleasurable sensations which we term "music." The thought suggests itself that the impacts transmitted to the neurones, *i. e.*, the vibrations, are of such a character as to be taken up by the molecules of the neurones without causing a disruption of

their structure, or, at most, only a minimal consumption of substance. It is probable that sounds which are harsh, discordant, cacaphonous, are painful because they actually cause destruction of the neurone molecule. Consumption of substance accompanies all discharge of function (see p. 164), but impacts that result in motions that are possible to or are in harmony with the structure of the neurone molecule are probably accompanied by pleasurable sensations.[1] Possibly in some such thought as this is to be found the explanation, also, of the pleasure and pain experienced through the other senses.

May we perhaps be permitted further to extend this conception to pleasurable and painful emotions? How markedly the latter are at times attended by the evidences of physical exhaustion—*i. e.*, consumption of substance—need hardly be pointed out. The relation between general nutrition and a sense of well-being is well known. Many factors,

[1] Taste in music and in other forms of art must not be confounded with the elementary pleasurable sensations. Taste in art is a very complex abstraction and varies greatly in time and place; for instance, the compositions of Mozart now considered exquisitely beautiful were at first not "appreciated" and the same is even more true of the massive drama music of Wagner.

however, enter into the problem, and a detailed consideration of the affective qualities of mind would lead us too far afield. Suffice it to say that the elemental qualities of pain and pleasure were in primitive forms doubtless related, on the one hand, to injurious or destructive influences, and, on the other, to the intake of food and other physical compliance with the needs of the organism. Later, in the course of evolution, there ensued specializations and differentiations of impressions, impressions derived both from the external world and from the body of the organism itself. At the same time special receptors, both extero- and interoceptors, together with special neurone pathways were evolved. Later, as has already been pointed out, with the increasing development of the telencephalon, there came a further differentiation in the impressions and their corresponding neurone reactions, and an increase in the adjustment of the responses, *i. e.*, in the behavior of the individual. Into the final result there may have entered, on the one hand, physical pain or physical pleasure; or, on the other, joy, satisfaction, sorrow, disappointment; or, it may be, a refined feeling of altruism or

perhaps of an almost impersonal regret. Here we have the birth also of the moral or ethical sense. Certain impressions give rise to distressing feelings not because the impacts excite pain in the nuclear aggregations of the thalamus, but because of the special character of the neurone associations which are formed in the cortex. For instance, we will suppose that transmissions have been received through those nuclear aggregations in the thalamus which are concerned in the basic tropisms upon which the instinct of love by the mother for the child is founded. We will suppose, further, that these transmissions lead in a given instance to neurone associations in the cortex which depart widely from those habitually and normally formed. Instead of having to do with feeding, care, protection, they now deal with neglect, with abandonment, with injury, with the murder of the child. Reflected again through the corticothalamic fibers to the thalamus (see p. 136), they now give rise to the feelings of pain and distress, and finally to the cortical outgrowths of these feelings, horror and revulsion. Herein, I believe, lies the explanation of the moral sense.

Both the thalamus and the cortex have played a rôle in its evolution. As before, the greater importance must be assigned to the cortex; especially the inhibitory rôle. On the other hand, if the thalamus be deficient in development, the "feeling" is deficient. If the latter be the case, crime may be committed often with great skill and ingenuity, but without a feeling that the action is "wrong," "immoral" or "wicked."

Not only does the degree of the thalamic and of the cortical development and the interplay of these two structures play a rôle in gross crimes, such as murder, assault, arson, but also in theft, dishonesty, deception, and, in fact, in all breaches of the social laws and conventions. The social laws and conventions are the outgrowths of the conditions which gregarious living has imposed upon mankind. Their breach is harmful to the community, but also in its final results to the individual. The "feeling" which the breach or the thought of the breach arouses, together with the cortical reaction, is the restraint which is automatically exercised.

Further, the interaction of the thalamus and cortex leads, under given conditions, from the

purely negative attitude of restraint and abstention from acts that are harmful to others, to the positive attitude of doing things which are intended for the good of others. The conception of pain and suffering may be so vivid as to lead to positive efforts for their alleviation in others. This is the source and origin of acts of charity and of the establishment of eleemosynary institutions. At times the conception of the wants and needs of others leads to self-abnegation and self-sacrifice; at times, again, to gifts and foundations whose object is the benefit of the fellow-man.

Another aspect of the interaction of the thalamus and cortex, as already indicated, is that presented by the development of the æsthetic sense. Sensations aroused in given nuclear aggregations of the thalamus and transmitted to the cortex, there undergo synthesis, analysis, discrimination (see p. 137). Discordant or pain-giving factors are rejected, concordant or pleasure-giving factors harmonized. Sense of beauty, artistic feeling, "taste," are the outcome.

XVI

PHYSICAL CONCEPTIONS IN THE INTERPRETATION OF MIND

In the preceding pages the writer has endeavored to apply purely physical conceptions to the interpretation of mind. As we have seen, the constitution of living protoplasm is such that only certain modes of motion can be accepted by it; namely, contact, coarse vibrations, the vibrations of light and heat, and the molecular motions which we term chemical. To all other modes of motion protoplasm is "transparent" (see p. 47). These facts demonstrate conclusively that its relations to the outside world are physical, and, further, that such forces as it does receive are admitted without interference with each other; just as a body in the external world may at one and the same time accept the vibrations of sound, of light, of heat, and of chemical change. The view that mental phenomena are in their essence physical finds confirmation in the facts of so-called psychophysics. These embrace especially the

results of the experimental study of the time relations of mental processes and of the phenomena underlying the sense impressions. While a consideration of these phenomena in detail would here be out of place, let it suffice to say that as regards the first, namely, the time relations or reactions—the time required for the response to sense impressions—they are significant in the fact, first, that *any time at all* is required, and secondly, that this time is in distinct relation to the complexity of the experiment and the condition of the individual; *i. e.*, whether the latter be in good health, whether he be fatigued, or perhaps under the influence of some stimulant or drug, or the subject of disease. Clearly, all these factors are physical in their nature. In this connection the interesting facts of the "personal equation" in the making of astronomical and other scientific time observations also present themselves. We are forcibly reminded, too, of the part which the synapses play in the delay of responses; though it goes without saying that some time must necessarily also be consumed in the transmission through the dendrites, bodies, and axones of the neurones.

It is, however, in the field of the experimental studies upon sense impressions that the most significant and most convincing results have been achieved. It was found, for instance, that a sensation aroused by a given impression having been noted, an increase in that sensation can only be brought about by a proportionate increase in the intensity of the impression. It was found, further, that in order to bring about such an increase of sensation, the increase of intensity of the impression made upon the receptors must be in a geometric ratio to the increase of sensations; that is, the intensity of the sensation increases in an arithmetic progression, the intensity of the stimulus in a geometric proportion. Thus, a man capable of distinguishing between the weight of 16 ounces and 17 ounces, cannot distinguish between 32 and 33 ounces, but only between 32 and 34 ounces. Again, a man capable of distinguishing between 20 and 21 grammes, testing a weight of 250 grammes cannot tell when an increase is reached until 12.5 grammes are added. If he looks at a light of 10 candle-power he cannot become conscious of an increase in the intensity of the

light until 2 candle-power are added; if he looks at a 60 candle-power flame 12 candle-power must be added; if it is a 2000 candle-power light, 400 candle-power must be added.[1] Similar facts obtain as regards the appreciation of intensity of sounds and as regards intensities of pressure. As regards the senses of taste and smell, of temperature, and the various somatic and visceral sensations, the conditions are such as to preclude very satisfactory experimentation. However, in regard to the senses in which such studies are possible, there can be no doubt as to the facts. A physiologist of a past generation, Weber of Leipzig, discovered these facts more especially in regard to auditory and cutaneous sensations, and they constitute what is today known as Weber's law. Many studies have since been made and various interpretations advanced, *e. g.*, by Wundt and by Fechner, and the facts may be briefly summarized as follows: an increase of sensation depends, as above stated, upon a proportionate increase of the stimulus; the increase of sensation is in arithmetic progression, that of the stimulus in geometric progression; or, to state

[1] Ebbinghaus, Abriss der Psychologie, 1909, pp. 66, 67.

it in other words, the sensation increases in proportion to the logarithm of the stimulus.

Clearly we have here a hint not as to the relations between physical impressions and a spiritual world, as various interpretations would lead us to believe, but a hint as to the structure of the proteins that make up the neurone and the physical laws which these proteins must obey. In a sense Weber's law is as purely physical as the one which tells us that light is inversely as the square of the distance and must be equally accepted. The facts of Weber's law, however, lead—it seems to the writer—to inferences far more fundamental and important. We have already seen that the number and character of the impacts which living protoplasm can take up is comparatively small. Only in an extremely limited degree do the changes induced in the protoplasm represent the changes—the multiplicity of forces—in the outside world. To this conception Weber's law adds another, namely, that such changes as are represented are only approximate; the very constitution of the protein molecules forbids an even and continuous recognition of the increasing intensity of impacts. If this be true

of the recognition of so simple a quality as increase of intensity, may it not be true also of other qualities of the impacts? The thought that suggests itself is that the changes induced in living protoplasm by the impacts are, *first*, only such as the protoplasm is capable of receiving and, *secondly*, that these may and probably do in themselves correspond only imperfectly to the changes going on in the outside world. We can only be conscious of the changes in the protoplasm of our own substance, *i. e.*, the changes in the proteins of our neurones; our knowledge of the outside world is necessarily limited to these changes and must of necessity be imperfect. Further, our knowledge is purely inferential. That multiple qualities of the outside world produce no changes in the proteins of the neurones we have already seen; that other qualities induce changes which only imperfectly represent those of the outside world is, it must be conceded, equally true. What are we to say of the memory pictures and of the general and abstract conceptions based upon these? Of the memory pictures it may be said that they can at best represent only more or less approximately actual past re-

sponses to impacts. Of the general conceptions—*i. e.*, the composite pictures, the composite combinations resulting from accumulated responses—it may be said that they are at best imperfect approximations to general external truths and are liable to vary and change with additions to the impacts and corresponding fresh responses; that is, with an increasing experience. When we approach the field of abstract conceptions we clearly tread upon dubious ground. In reality, abstract conceptions represent nothing that actually exists in the outside world. At most they are artificial pegs upon which to hang the logic of our ideas. And, as regards our logic, is not this faculty dependent upon our own structure, upon the arrangement of our neurones, and upon their contained proteins and other substances? In how far is it to be trusted? Does it not at times lead us into gross absurdities? We need but recall the time-worn story of the race between the hare and the tortoise. Each interval of space existing between the two is divisible, and no matter how small the space may become it is still divisible; indeed, it is inconceivable that the

space should become so small that it should not be still further divisible; and so it becomes *logically* impossible for the hare ever to catch the tortoise. Similar vagaries of neurone activity doubtless lie at the basis of such abstractions as the fifth and sixth dimensions of space. As regards the fourth dimension, Einstein, after pointing out the relations of a given body to the three classical dimensions of space, points out that all bodies in the universe are in motion, and as it takes time for a given body to move from one point to another, time is the fourth "dimension" of space. Time and the three classical dimensions are abstract conceptions, but the conception of "dimensions" having once been admitted, it becomes logically capable of indefinite multiplication; hence the fifth, sixth, and further dimensions of space. Is there not here an analogy to the logic of the race between the hare and the tortoise? In one instance there is indefinite division, in the other, indefinite multiplication.

Evidently the logical process must be constantly curbed, held in check, inhibited by the correcting influence of the impressions received from the external world. We *know*

that the hare *does* pass the tortoise, and we know also, no matter what our mathematical friends may say, that the indefinite multiplication of the "dimensions" is in crass contradiction with the orientation of our senses, *i. e.*, with human experience.

XVII

THE NERVOUS SYSTEM IN THE LIGHT OF EINSTEIN'S INTERPRETATION OF ENERGY

It has seemed to the writer for some time past that Einstein's interpretation of energy must have a universal application. If so, it must include the phenomena presented by living matter. Stripped of its mathematical formulary and reduced to its simplest expression, Einstein's position may be briefly stated as follows[1]: Einstein begins with the three classical dimensions of space, *i. e.*, three planes placed at right angles to each other like the floor and two sides of a rectangular box. The position of a given body can be readily determined by measurements from these three planes. However, to repeat the statement

[1] This statement is the interpretation derived from a consideration of the writings of Einstein; from Malcolm Bird's compilation of Einstein's Theories based on the essays submitted in the competition for the Eugene Higgins Prize and published by the Scientific American Publishing Co., New York, 1922; from James Hopwood Jean's admirable presentation of the subject in the Encyclopædia Britannica, New Volumes, Vol. XXXII, 1922, p. 261, from Benjamin Harrow, Newton to Einstein, D. Van Nostrand Co., New York, 1920; and from other sources.

made in the preceding chapter, inasmuch as everybody in the universe is in motion, it necessarily takes time for a given body to move from one point to another. Time is therefore another measurable factor and it constitutes the fourth dimension of space. Again, the number of bodies in the universe is multiple. A given body coming within the gravitational field of a second body cannot continue to move in a straight line; necessarily its motion becomes curved. Motion in straight lines in the universe is unknown; all motion is curvilinear. All bodies necessarily move in relation with the four dimensions of space. The course of a body is its only possible motion; its curve represents the shortest possible distance between two points; it is the analogue of the straight line of Euclidian geometry. Technically it is known as the "world line" or geodesic.

Let us pause for a moment to consider some of the elemental facts of our abstract modes of thinking. First, we speak of a point. A point as such, it will be at once conceded, is an abstract conception. A line consists of an infinite number of points arranged in sequence. A line, also in this sense, is an abstract concep-

tion. A plane consists of an infinite number of points arranged in the relation of two dimensions. A plane, in its turn, is an abstract conception. As soon as the conception of a third dimension is added, it ceases to be a plane. Finally, points, lines, and planes are all abstract conceptions, none of which has any existence in the outside world. I can move my hand up and down, to and fro, and from side to side, but I am conscious of the fact that there are neither lines nor planes in the outside world to correspond to these motions. These are only abstractions in my own mind. I am conscious, too, that it takes time to make these motions, and the only factors of the reality of which I have convincing proof are the two facts of space and time, and these, as we have just seen, are in nature inseparable. That which is about me is the space-time continuum. It is the only objective reality. All else is abstraction. It alone is based upon experience.

Further, the term "space-time continuum" merely expresses the fact of moving matter. All space is filled with moving matter; nay, all space *is* moving matter. All space is coexistent and coeval with the space-time continuum,

i. e., with matter in motion. If there be no matter, there is no space. If there be no space, there is nothingness, and nothingness has no place in our problems. And when Einstein speaks of the curvature of space, he speaks of of the curvature of matter or, rather, of the curvature of the space-time continuum.

Euclid's interpretation begins and deals with fixed points, lines, and planes. Newton's interpretation begins with a body at rest or, at most, with a body moving in a straight line. No such things as fixed points, lines, or planes exist in nature; no such things as a body at rest or a body moving in a straight line exist in nature. Both interpretations necessitate conceptions which—to borrow a phrase from Herbert Spencer—are illegitimate. They both necessitate mental pictures which have no counterpart in reality. Einstein, on the other hand, starts with the universe as it actually exists. He starts with moving matter, with matter moving in relation with space and time. In other words, he begins with the ever-moving, ever-changing space-time continuum, a continuum in which we are immersed and of which we form a part.

The outcome of these conceptions is to bring to light the difference between the abstract conceptions of the plane geometry of Euclid and the actual findings in nature. While the theorems of Euclid are, of course, true in the abstract, they are only relatively true in their concrete application, and we are not surprised to find that the shortest distance between two points is not always a straight line, that the sum of the angles of a triangle is not always one hundred and eighty degrees, or that the angle of a square is not always ninety degrees. Euclidian geometry is, of necessity, static; Einstein has converted it into a moving, a living, a dynamic reality.

Bodies move not, as we have seen, in straight lines; their speed and direction of motion are constantly changing. To these changes the term "acceleration" is applied, which means either that the speed is increasing or diminishing or that its direction of motion is changing, or both.[1] Newton began with a body at rest or pursuing a uniform motion in a straight line;

[1] The special theory of relativity postulates the theory of uniform motion. The general theory deals with motions that are not uniform. All bodies are under the gravitational influence of other bodies and this leads to "acceleration" of motion.

Einstein began with the world line of the four dimensions and deduced therefrom the observed facts of gravitation. The world lines, occupying the four dimensions of space, consist necessarily of space-time combinations. They are strained and distorted due to the attraction that bodies exhibit for one another. In other words, the phenomena of gravitation express the strain of space-time combinations. The influence of acceleration and the relativity of gravitation is seen in the following familiar illustrations: A revolving axis such as is seen in the old-fashioned governor of a steam engine, which has attached to one extremity a rigid though freely movable arm, permits the arm to lie close to the axis when the axis is at rest, but when the axis revolves, the arm is thrown out, and, in proportion as the speed of the revolution of the axis increases, the arm is thrown farther and farther from the axis. Again, it has been calculated that if the earth's rotation were increased 17 times, Newton's apple would not fall in a direction toward the earth's center, but would pursue a course parallel to the axis of the earth. If the rotation were increased very much, the apple would pursue a course away from the

earth at right angles. The reverse, of course, obtains with the slowing of the speed of rotation. In either instance we observe the effects of "acceleration." Again, in Einstein's hypothetical experiment of a man enclosed in a falling box, if the man and box fall at the same rate, the man experiences no sense of weight relative to the box and he might occupy any position in the box, in contact with the floor or the roof of the box, or occupy a position not in contact with either. Weight would only become manifest upon a change in the rate of the fall of the box. Obviously, too, in such a box the pans of a pair of scales would reveal no difference between a pound of lead and a feather. Everything depends upon the fact of "acceleration."

Further, every particle of matter travels through the space-time continuum in the most direct possible path, *i. e.*, through its world line or geodesic. It would appear then that the course of such a particle is dependent upon the inherent structure of the space-time continuum. If this be true, it must explain not only the phenomena of gravitation, but all other phenomena as well. Clearly, this prin-

ciple must apply to all bodies large or small. It applies to the motions of the planets, on the one hand, and to the movements of the electrons about the nucleus of the atom on the other. It would seem to apply alike to the coarse mechanical effects of gravitation and to the more recondite phenomena of chemical action, electricity, magnetism, and light. It would seem, as regards forces other than gravity, that the latter are merely the outcome of the details of the curvatures, *i. e.*, of the geodesics, traversed by the particles in motion. Such details appear to add merely to the complexities of the problem, but do not alter its principle. Such a view has already been advanced by H. Weyl and his predictions coincide completely with the known facts of the electromagnetic forces. It would appear that all of the expressions of energy are but maelstroms, whirlpools and eddies in the mass of the space-time continuum in which we live.

It seems a far cry from the consideration of these problems to the phenomena presented by the nervous system of animals. However, here again, as we have seen, problems of motion present themselves, problems of impact, of

transmission of responses. To the observer who regards the universe as a whole, the problems presented by the world of living things cannot differ in their essence from those presented by non-living things. The fundamental principles applicable to one cannot differ from those applicable to the other.

We have already considered the phenomena of the transmission of energy through living matter; first, as we find it revealed in the simplest forms of life, such as the amœba, the sponge, the jelly-fish, the sea-anemone and, finally, as we find it revealed in vertebrates. Lastly we have presented the conclusive evidence that this form of energy is electrical.

The inference is, I believe, inescapable that the phenomena of living protoplasm must be interpreted in the same terms as the other phenomena of nature. It would appear that this is clearly indicated in the transmission of impacts. If electrical change, ionization, constitutes the underlying fact of such transmission, such transmission is clearly expressive of the same force or forces which we see about us in the inorganic world. That the forces of the latter are dependent upon and inherent in the

structure of matter, that is, inherent in the very structure of the space-time continuum itself, is clearly revealed by Einstein's interpretation, and the inclusion of the problems of living matter in the same category robs the latter of much of its mystery.

The investigations of Thomson, Rutherford, Milliken, Aston, Moseley, Bohr, and many other physicists, have demonstrated conclusively the structure of matter. The atom has been definitely resolved into its nucleus and revolving electrons. The nucleus, also termed "proton," is electro-positive, the electrons being electro-negative. The structure of the atom of an element, other things equal, depends upon the number of its revolving electrons; thus the hydrogen atom possesses but one, while the other elements possess electrons in a progressively increasing number until we reach the heaviest and most complex of them all, uranium, which has 92 electrons revolving about its nucleus. It has even been possible to reduce the number of electrons of a given element and thus to change it into another. The very structure of the nucleus has been studied and is revealed as being made up of both electropositive and

electronegative factors, the electropositive predominating. The conclusion is inevitable that the atom with its nucleus and electrons is but a manifestation of electricity.

The interpretation of the structure of matter and the interpretation of the universe opened up by Einstein must greatly influence our conceptions regarding living forms. The basic distinction between living and non-living substances disappears. Our age-old conceptions regarding non-living matter—inorganic matter as we call it—reveal themselves to be hopelessly at fault. The universe is in no part and at no time "dead" or "inert." Taken in its entirety or in its most minute subdivisions, it reveals itself in its ultimate analysis to be an expression of energy. Everywhere it reveals itself to be a moving, pulsating, throbbing, "living" thing, a thing in which we are immersed and of which we ourselves form a part. It certainly does not seem philosophical to regard those moving molecular aggregates which we term living forms, no matter how integrated and differentiated they may be, as things separate and distinct from the rest of the universe. Assuredly it does not seem necessary to evoke

special agencies to account either for their existence or for the phenomena which they present. One of the generalizations held out to us by the conception of the universe here outlined, is that of a whole, all parts of which are expressive of manifestations of energy; manifestations cognate and correlative and intrinsically identical. Of necessity such a conception must include living matter.

An interpretation of mind based on biological and physical considerations leads, I believe, to a more wholesome, a saner conception of its nature, of its functions, and of its limitations. It may be noted that in this essay, up to the present moment, the word "psyche" or its equivalents and derivatives have not been employed. At the very outset the necessity was pointed out of laying aside preconceived ideas, prejudices, and beliefs. To introduce at this point an "immaterial" something, of unknown and unascertainable character, to insert such a something into the problem renders the latter hopelessly unintelligible. Further, when we pause to consider the intrinsic meaning of the

word psyche and its equivalents, most suggestive inferences present themselves. The Greek word ψυχή has the primitive meaning of the *breath:* indeed, given the Greek pronunciation, the sound is literally that of the escaping breath. In primitive times the "breath" was looked upon as the vital principle, and its final escape in the act of dying as the departure of that vital principle. The ψυχή naturally and subconsciously represented the idea of an "immaterial" constituent of our beings. A similar interpretation is applicable to the Latin word *spiritus,* the primitive meaning of which is likewise air, exhalation, breath, and its root still forms the integral parts of the words respiration, inspiration, expiration. The Latin word "mens" is free from such objections, for it literally means the mind, the understanding, the intellect, and to me it has seemed much more fitting to employ its derivatives than those derived from ψυχή or from spiritus.

In conclusion, I may perhaps be permitted to say that there is nothing in the position here assumed which should shock or give pain to any one. The study of the recondite problems

of human existence is in a sense a study that is imperative and should be pushed to its ultimate conclusions. Our knowledge of the constitution of the universe as revealed by the marvelous truths of radio-activity, of the structure of the atom, and by the field opened up by Einstein's discoveries and theories, is but an expression of this tendency; surely it should not be denied us in the study of mind. The modern study of the atom reveals it to be but an expression of energy, indestructible, persistent, unknowable. Does not this cause the difference between the old conceptions of "material" and "immaterial" to disappear? Does it not make unnecessary as it is impossible—a "dual" conception of the universe? Finally, we should remember, that as regards religious conceptions, each human being is entitled to hold such faith as he chooses, and, further, that it is the necessary and essential attribute of religious faith that it should be incapable of scientific proof. A religious faith that would be capable of mathematical demonstration would be no faith at all.

ADDENDUM

XVIII

THE PATHOLOGICAL PHYSIOLOGY OF MIND

An application of the facts and deductions embraced by the within essay to mental disease is both obvious and interesting, and the writer has thought it fitting to add the following paragraphs.

In the body of the essay, the writer has pointed out how the retraction of the dendrites and axones of the neurones explains the palsies and anæsthesias of hysteria. In other words, the functional break is referred to the synapses. A similar explanation applies to the palsies and anæsthesias of hypnosis which, as Gilles de la Tourette long ago pointed out, is merely hysteria artificially evoked. All of the phenomena of these states are undeniably mental, *i. e.*, cortical in their origin. This is true alike of the motor, sensory, visceral, as well as the more strictly mental reactions. In hypnosis,

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for instance, a partial sleep is induced in which the admission of impacts from the various receptors is inhibited save from those of the sense of hearing. The instructions, *i. e.*, the suggestions, are made orally by the operator[1]; all other avenues of contact with the outside world are for the time being closed. The train of neurone activity, therefore, which is set in motion by the suggestions of the operator pursues its way unchecked, uncorrected, for the impressions ordinarily received through vision or the other senses cannot gain access to the train of neurone activity, the field of consciousness. That under such circumstances the subject should prove to be exceedingly susceptible to the suggestions of the operator is not surprising; even when the suggestions are in crass contradiction with the situation in which the subject happens to be placed and with his previous experiences.

The patient suffering from hysteria while not in any sense asleep, as in hypnosis, yet resembles the hypnotized subject in being abnormally susceptible to suggestion. Both Charcot and Gilles de la Tourette long ago

[1] Except, of course, in special instances.

stressed this factor in their descriptions of hysteria. It was Babinski, however, who especially pointed out the fact that the symptoms have their origin in suggestions that may arise from causes within as well as from causes without the patient. Especially instructive also were the facts which Babinski presented in regard to the production of special symptoms by the medical examination itself. He pointed out, for instance, that the reason hysterical hemianæsthesia predominates on the left side of the body is because the physician, being usually right-handed, has the brush or æsthesiometer in his right hand, and, facing the patient and asking the usual questions, he naturally tests the left side of the patient's body first; thus suggesting the very anæsthesia he is trying to discover. Similar facts obtain in regard to the induction of other sensory losses and other symptoms. The fact, however, of greatest importance is that the same or similar procedures may be practised upon normal persons, but without the slightest result. In other words, the hysterical subject accepts suggestions both direct and indirect; the normal person repels them. The personality of the hyster-

ical patient is a very vulnerable one. Hysteria is, indeed, a neuropathy of degeneracy. Its symptoms are always expressive of a biological inferiority, and, in keeping with this fact, it presents a large element of heredity. Charcot and his pupils regarded hysteria as always inherited; all other causes have merely the value of provocative agents. It would appear that, as in hypnosis, impacts received by receptors other than those which serve as the entering avenue of the suggestion, fail to reach or to adequately enter the train of transmission, the field of consciousness. It is a matter of common experience that when the suggestion giving rise to the symptom ceases to be operative or when the conscious field is entered by countersuggestions, as in psychotherapy, the symptom disappears. It is not my intention here to consider the mechanism of hysteria in detail; such, for instance, as is illustrated by the immediate disappearance of the hysteria of litigation when the claim is settled or otherwise disposed of, or, of cases in which other "mental compensation" equally powerful occurs; for this would take us too far from our subject.

The discussion of the phenomena of hypnosis and of hysteria leads naturally to the discussion of dreams; the latter, it should be added, however, may be entirely normal manifestations.

In a dream, as in hypnosis, a group of neurones are active, constituting a field of consciousness. However, as in hypnosis, impacts from the special sense organs are excluded. Such a group of neurones may be roused into activity by the entrance of impacts from the interoceptors and proprioceptors; *i. e.*, from the viscera or from the body generally. Such impacts may have their origin in disturbances of the digestive tract, or of the urinary or of the sexual apparatus. Again, it may be that the cause consists of the presence of special substances circulating in the blood, such as substances resulting from overfatigue, substances absorbed from the digestive tract the result of indigestion, or possibly substances due to disturbances of metabolism; or other materials toxic in their nature which have found entrance into the circulation. However, no matter how arising, the mechanism of the dream is probably as follows: Due to visceral or other somatic impacts, or due to the direct action of substances in the

blood, given nuclear aggregations in the thalamus are roused into action. Necessarily transmission to the cortex follows. Transmission in the cortex being uninhibited, *i. e.*, uncorrected, by impacts received from the external world, now diffuses along pathways of least resistance; former neurone combinations are re-formed, many former ones are compounded; unusual and bizarre combinations result.

Considerations such as the above lead naturally to a consideration of states of delirium and confusion. Here we have to deal with problems of infection, intoxication, and exhaustion; and doubtless with the action of toxins and poisons both upon the synapses and upon the bodies of the neurones. Irregularly occurring, constantly changing combinations, discharges and retractions appear to feature the conditions; more active and pronounced in delirium; delayed, slower in confusion; and abolished in stupor. In keeping with this interpretation, we find delirium featured by hallucinations, illusions, and unsystematized, fragmentary delusions. A hallucination is a sensation which arises spontaneously without any impact being received from

the external world. As in the dream, we are dealing with disturbing causes affecting primarily the nuclear aggregations in the thalamus and with the transmission of these disturbances to the cortex. Quite frequently these disturbances involve the nuclear aggregations of the special senses; for example, of hearing and vision, or it may be of taste and smell. Forcing their way into the train of activity already present in the cortex, they are naturally regarded by the communal consciousness (see p. 113) as things coming from without, and the noises, words, or phrases heard or the object seen are referred to the outside world. That in delirium errors of perception also occur is not surprising. An illusion—excluding, of course, errors in the receiving apparatus, the special sense organ—is due to a faulty combination of the neurones of the cortex in response to the impacts received; or to an imperfect or aberrant correlation (integration) with combinations previously formed; thus occur mistakes in the recognition of objects and persons. That the resulting state of the communal consciousness should be one of confusion more or less active according to the intensity of the disturbance is what we

should under the circumstances be led to expect.

It is one of the essential features of delirious and confused states that there is an absence of fixation of any of the symptoms. The picture is one constantly changing, constantly varying; in an active delirium the picture changes with kaleidoscopic suddenness; in confusion much more slowly; while in stupor the deadening weight of intoxication and exhaustion abolish all manifestations whatever.

In certain mental diseases fixation, on the contrary, sooner or later makes its appearance. In order that the significance of fixation may be fully appreciated, a digression will be necessary.

There is a group of mental diseases which have their beginnings before the foundation of the organism is laid. The building material is imperfect, poor in quality, vitiated, so that the resulting structure crumbles and gives way under its own strains. Mental symptoms make their appearance relatively early, and this caused the early French writers, notably Morel, to speak of it as *démence précoce*, a name which Arnold Pick long after rendered into the now

generally accepted term "dementia præcox." As might be expected, the number of factors which enter into the impaired heredity of the patients is exceedingly large and varied, *e. g.*, mental and nervous disease, syphilis, alcoholism, criminality, prostitution, vagabondage, eccentricity; in fact, all forms of degeneracy, misfits, and failures. As might almost be expected, cases of dementia præcox present in varying degree evidences of an imperfect or incomplete development. The evidences of arrest and deviation are usually quite numerous. Their frequency has been placed as high as 75 per cent. We note such pictures as physical feebleness, retardation of growth, prolonged juvenile appearance, peculiarities in the shape or malformations of the skull, deep and narrow hard palate, persistence of the intermaxillary bone, abnormalities of the limbs and digits, anomalies of dentition and other peculiarities that might be mentioned.[1] In keeping with these anomalies of structure accessible to ordinary observation, we find also deeper and underlying anomalies of the glands of internal secretion and the disturbances of metabolism which these anoma-

[1] Dercum, Biology of the Internal Secretions, Section XIX.

lies imply. The significance of these facts is, of course, beyond question, and that an organism so imperfectly constituted should break down from the mere strain of living should occasion no surprise.

Dementia præcox is essentially an affection of endogenous deterioration. It should really be spoken of in the plural as the insanities of adolescence, because in keeping with the many and varied hereditary factors entering into its causation, it manifests itself in many forms. Long ago two groups were isolated by Kahlbaum, which he termed respectively "hebephrenia" and "catatonia," and to these Kraepelin later added a third, "paranoid dementia." Later still Kraepelin distinguished ten different forms instead of three, but in this he has not been generally followed and doubtless largely because, as Kraepelin himself admits, there are between the various groups so many transitional forms that they cannot be sharply delimited. For practical purposes, the segregation into hebephrenia, catatonia, and paranoid dementia, is quite commonly accepted. Hebephrenia is a relatively simple form, which occurs, on the whole, in the younger individuals;

catatonia is distinguished more especially by the addition of certain motor phenomena and also presents slight evidences of "systematization" of the delusive ideas, and occurs, on the average, in somewhat older patients. Paranoid dementia is distinguished by a more pronounced systematization and occurs, on the average, in a still older group. That many transitional forms are met with need hardly be restated.[1]

Space and the objects of this Addendum do not permit of a consideration of the symptoms of dementia præcox. Suffice it to say that the facts in our possession point clearly to a progressive biological deterioration in which, among other things, endocrine failures and exhaustion play prominent rôles.[2] The onset of symptoms is gradual, usually bearing the character of a confusion, sometimes with varying elements of systematization, and, let us re-

[1] Because of his interpretations of dementia præcox as a cleavage or fissuration of the mental functions Bleuler invented and proposed the name "schizophrenia," which be believes to be preferable to dementia præcox. However, cleavages and fissurations of the personality are not confined to dementia præcox, but also occur in other forms of mental disease as well as in the neuroses. Both the term and the affection lack the specificity that would justify its use.

[2] Dercum, The Story of Dementia Præcox, New York Med. Jour., Aug. 12, 1916; also Clin. Manual of Mental Dis., 1918, p. 108.

peat, of weakness and exhaustion. That a final dementia should ensue seems quite natural; and it is this that occurs in the larger number of cases.

The behavior of the neurones, their synapses, and cell bodies in confusion we have already considered. Feebleness and irregularity of endocrine development imply toxicity, and together with this we have a nerve substance inherently defective and feeble in resistance. As a natural result there is present, in addition to the confusion, a more or less marked adynamia of the field of cortical activity, the train of transmission. The level, the intensity of the metabolic processes of the neurones is lowered. In keeping with this, there is slowness of speech and poverty of thought which eventuate in mutism, in fixed positions, stereotypy, automatism, perseveration, verbigeration; or it may be in stupor. Some of the symptoms, such as the fixed positions, the stereotypy, the automatism, the perseveration, are to be referred to the motor structures of the segmental brain; others, of course, to the cortex. In the latter the train of transmission is reduced to a shallow, a narrow, a monotonously trickling

stream, which may for a time cease altogether. Now and anon tributary currents join what is left of the main stream, but they do so irregularly, at unusual points, and at variance with the orderly sequence of neurone combinations. While the cortex is adynamic as a whole, it may happen that the field of cortical activity is more greatly reduced than other portions. Under normal conditions the train of transmission, as already pointed out, diffuses, discharges into other and still inactive areas. However, if the level of the active field is greatly diminished and other portions of the cortex become, as a result of the toxic causes at work, spontaneously active, and if they possess relatively greater dynamic power, the direction of the diffusion may be reversed and these new activities may flow into the less resistant field. It is not necessary to suppose that they represent "complexes" that have been "repressed," to use the language of the Freudians. They may, of course, represent a variety of things; on the one hand, "wishes" and things desired, and, on the other, things of which the patient stands in fear and dread; but not necessarily of either.

We have already traced the origin of a hallucination, *e. g.*, of hearing, and how it breaks into the train of transmission and how it is naturally regarded by the already existing communal consciousness as something coming from without. In a similar manner, other groups of neurone combinations may, as a result of their greater dynamic level, diffuse their energy into the less active field. That phenomena of cleavages and fissurations of the personality should under these circumstances result is what might be expected, but this is no reason, as has already been pointed out, for giving to dementia præcox the specific name of schizophrenia.

Let us return now to a consideration of fixation which in certain mental diseases sooner or later makes its appearance. We have seen how in delirium and confusion there occurs an ever-changing and ever-varying combination among the neurones. Synaptic relations are continuously and irregularly made and broken. We have seen, also, that in dementia præcox, especially in the younger group, the

mental picture is that of a confusion, but that in the older groups "systematization" of the delusive ideas may in some degree be present. By systematization is meant the arrangement of the ideas into logical sequence; in other words, a systematized delusion is one which has a logical structure. Now, it is the essence of an insane delusion that the person holding it is incapable of accepting evidence concerning it; *i. e.*, such evidence as is accepted by ordinary men or by normal minds. This can only mean that the neurone combinations concerned in the delusions are inaccessible. It is entirely justifiable to assume that we have here to deal with relations between neurones which recur with such ease and constancy as to be potentially fixed in character. Inaccessibility to conflicting trains of neurone combinations is a necessary result. Any impulse approaching the neurones concerned merely results in the reformation of the old combinations. In keeping with this we meet with another fact, and that is, that a delusion once fixed becomes permanent. This is typically illustrated by the history of the various forms of delusional lunacy or paranoia, as it is technically termed;

and, indeed, it may be stated, that the appearance of systematized delusions in a given mental case is always an unfavorable omen.

Like dementia præcox, paranoia presents the evidences of gross morphological arrests and deviations. Like dementia præcox, it presents a large element of heredity, and like dementia præcox it is a degenerative affection. It is especially featured by a slowly progressive, dementing process.[1] The delusive ideas become gradually more and more firmly established, until finally they become fixed and unchangeable. For instance, in regard to a given matter which deals, it may be, with the persons about the individual or with his position in life, the neurones are incapable of forming other than *one* combination, and this is the *same constantly recurring* combination. The neurones and especially their synapses have lost their former freedom of play. Impacts leading to new combinations, *i. e.*, to other points of view, no longer find entrance.

In many forms of paranoid degeneration, the case is especially featured by the presence of hallucinations more or less marked in character.

[1] Dercum, loc. cit.

They are apt to make their appearance early in the history of the affection and persist in greater or lesser degree throughout. As in delirium, these hallucinations appear to have their origin in disturbances—excitations—of the nuclear aggregations in the thalamus. Inasmuch as these nuclear aggregations, save those receiving impacts from the intero- and proprioceptors, are normally aroused by impacts received from without, these sensations when transmitted to the cortex are, of course, referred to the external world. Further, they are painful and distressing. At times they are intensely so. They may consist of offensive, disgusting, foul odors and tastes, of noises and other disagreeable sounds, of various abnormal visual impressions, of strange visceral or bodily sensations. It does no violence to assume that these abnormal feelings are due to degenerative changes in the neurones of the nuclear aggregations; perhaps to retrograde changes, failures in the metabolism of the cell contents; perhaps in disorders of metabolism which have their origin in failures of the internal secretions.[1]

When these painful sensations are transmitted

[1] Dercum, Biology of the Internal Secretions.

to the cortex they must necessarily give rise to combinations that are painful; the combinations certainly cannot be pleasurable. Further, these combinations must deal with matters in the outside world. What is more natural than that strange and disgusting hallucinations of taste and smell should give birth to the idea of being poisoned? Being poisoned, logically, requires a poisoner. Again, the painful auditory sensations of noises, cries or shrieks, sooner or later resolve themselves into words, words of curses and abuse. These words, which may assume the character of phrases or sentences, are naturally attributed to persons in the outside world; and here we have the birth of the delusions of persecution so characteristic of the fully developed period of paranoid affections. As already pointed out, the cortex is itself already diseased, and that the delusions become fixed and firmly established can be readily comprehended.

In the later stages of paranoia the depressive and persecutory ideas begin to fade; they become less prominent, and their place is taken by ideas that are pleasurable in their character. The individual may believe himself to be a

person of great consequence and importance. The very fact that he has been the victim of persecution proves it. Indeed, he has come to the conclusion that he was not born in the humble surroundings in which he spent his childhood and youth, but that he was substituted in the cradle, that the reputed parents are not his, that he was born amid wealth and distinction, and that he is really a great personage. These ideas betray the weakness inherent in the advancing degeneration. They are commonly grotesque, grossly absurd, and out of all keeping with the patient's surroundings. They are expressive both of a diminished capacity for pain and suffering and of the intoxication of a deranged metabolism.

There has been a disposition, following the lead of Kraepelin, to confine the term "paranoia" to a group of cases in which the delusive ideas were formed independently—so it was supposed—of the existence of hallucinations. In the earlier editions of his work on Psychiatry, Kraepelin included under the term "paranoia" the hallucinatory form which we have here briefly outlined, but later restricted the application of the term to cases not featured by hal-

lucinations, and in which the delusions are supposed to be based upon observations made of the external world, the delusions being the result of a faulty logical interpretation of the things actually seen and heard. Careful study of such cases has, however, convinced the writer that the basic cause of the disturbance is a derangement of the "feelings" of the patient; these suggest in their character the disturbances of the nuclear aggregations of the thalamus which give rise to generalized feelings of discomfort, distress, sense of ill-being, and kindred feelings. Such feelings are clearly hallucinatory in character. Further, in many cases of this form of paranoia, actual, frank hallucinations of the special senses are occasionally observed; now and then of hearing, sometimes of vision, and somewhat more frequently of taste and smell. The cortical disturbance observed in these cases is also of the same nature as that observed in the frank hallucinatory form. In the latter a misinterpretation of the impacts likewise takes place; faulty, incorrect inferences are drawn. Clearly, the logic of the patient is equally and even more grossly at fault than in the so-called non-hal-

lucinatory form. As in the latter, the patient also misinterprets the things which he actually does see and hear; though his hallucinations are so vivid and insistent that they force themselves unrestrainedly into the train of cortical transmission and therefore dominate the conscious field.

There is in the writer's opinion no valid reason for regarding the non-hallucinatory as radically different from the hallucinatory form. The mechanism of the gradual conversion of painful feelings and sensations into persecutory ideas is the same. As we would expect under the circumstances, the so-called non-hallucinatory form is much more slowly progressive while there is present for a long time a relatively high degree of lucidity. Finally, it may be pointed out that the occasional occurrence of cases which are intermediate and cannot be readily placed in either category is another fact in keeping with the view that a sharp line of separation should not be drawn between the two groups. Both are forms of autodegeneration. Both should be grouped with the general mass of inherently defective and progressively degenerative cases which present themselves at

one end of the scale in the simple form of dementia præcox and of lucid paranoia at the other. The latter even fade into cases in which the existence of actual mental disease is in doubt. Such cases, as is well-known, not infrequently form the subject of dispute in the courts.

Let us now turn our attention to melancholia and mania. Here we meet with mental affections which are featured neither by mental deterioration nor by the evidences of an incomplete and imperfect development. Their sole peculiarity consists in that the patient passes through wave-like periods of emotional depression, quiet, and exhaustion, or, it may be, of emotional expansion and activity. At the conclusion of such a wave-like period, no impairment of the mental integrity of the patient is noted save in instances in which special factors have been at work. Quite frequently waves of depression and expansion succeed each other, the patient passing through a cycle of the disturbance. In reality the two phases constitute one clinical entity to which the term "manic-depressive insanity" has come to be applied. Though presenting neither the evidences

of an arrested development nor the history of mental deterioration, the affection is, notwithstanding, featured by a very marked heredity. In 80 per cent. and more of the cases can a history of heredity be elicited. What is it that is transmitted? What is the basic cause of the disturbance? As the writer has pointed out, this is clearly to be sought in the glands of the internal secretions.[1] The latter separate themselves, as has been shown in the preceding pages, into two great groups—the autonomic and the sympathetic. The function of the first, let us repeat, is anabolic; it is concerned with the storing up of energy. The second is catabolic and is concerned with the expenditure of energy (see p. 165). In melancholia there is a great recession of function of the anabolic group, and, in consequence, melancholia is featured by nervous weakness and exhaustion, by atony and failure of the digestive tract, by reduction and feebleness of the circulation, by loss of weight and strength, and especially by mental depression. At the same time, we note that the expenditure of energy is reduced, and, at the height of the affection, to the lowest pos-

[1] Dercum, Biology of the Internal Secretions, Section XX.

sible level. In other words, the group of glands innervated by the sympathetic—the chromaffin system, the thyroid and the pituitary—are also reduced in function. A diminished storing up of energy must inevitably be followed by a diminished output. Doubtless their lessened activity is also to be ascribed to the accompanying diminution of the sympathetic innervation.

After many months of quiet, rest, and food, energy is slowly and gradually regained and the normal level of metabolism is again reached. Unfortunately in a large number of cases the anabolic changes do not stop, but with increasing impetus sweep beyond the normal line; the sympathetic group become excessively active, and restlessness and expansion now replace the previous depression.

Certain facts in regard to the mental symptoms must now be noted. The depression which accompanies the recession of function in the autonomic group in melancholia is not only physical but also mental. Indeed, as already stated, the characteristic feature of melancholia is the the emotional depression. This emotional depression assumes the form of mental suffering,

of mental pain. The feeling is akin to that which persons otherwise normal experience when subjected to sorrow and grief. This pain is clearly to be referred to the thalamus. The latter, as we have learned, contains nuclear aggregations which receive impacts from the various inter- and proprioceptors of the body. Under normal conditions the sum total and averaging of these impacts gives rise to a sense of well-being. However, in melancholia the impacts received from the organs concerned in reconstruction and the maintenance of energy—the impacts from the digestive tract with its important group of associated organs, the impacts from the heart and blood-vessels, and from the various glands concerned in the anabolic processes—these impacts, let us repeat, are greatly changed both in their amount and in their character. That the resultant feeling aroused in the thalamus should depart widely from that present in health, and that instead of being pleasurable it should be distressing and painful is readily conceivable. Further, it is exceedingly probable that the nuclear aggregations suffer in addition from an impaired nutrition and from toxicity.

Another interesting reaction is now noted. It will be recalled that in paranoid states the patient refers his distressing thalamic sensations to the outside world and develops delusions of reference, delusions of injury, delusions of conspiracy. In melancholia the exact opposite occurs. The patient refers the painful sensations to himself and develops ideas of self-blame, self-accusation, and, finally, the delusion of the unpardonable sin. The following explanation of this reference to the "self" of the patient now becomes obvious.

In the first place, the impacts which enter the nuclear aggregations of the viscera and soma generally give rise under normal conditions to transmissions into the field of cortical activity which merely convey a vague and generalized sense of contentment, satisfaction, and well-being. The train of transmission in the cortex is filled mainly with impacts received from the various exteroceptors of the special senses, *i. e.*, the field of consciousness is dealing mainly with the outside world; impacts from the soma normally enter it in but slight degree. However, when the somatic nuclear aggregations are abnormally aroused, or when their activities

are perverted, these impacts force their way into the field of consciousness in greater degree. They are now "hallucinatory," but being interoceptive and proprioceptive in origin, they cannot be referred to the outside world; necessarily they must be referred by the communal consciousness to itself (see p. 113). Some of the impacts received from the somatic nuclear aggregations are comparatively definite in character and lead to hypochondriacal sensations referred to this or that part of the body, this or that organ. Thus arise the various "visceral hallucinations." Hypochondriacal sensations, visceral hallucinations, enter into the symptomatology of melancholia in varying degree; sometimes slightly, sometimes largely. Especially is this apt to be the case in the melancholias of middle life. However, it is not a sense of the disturbed condition of the body that forms the characteristic feature of melancholia, but the presence of a painful emotion comparable to sorrow or grief and which may reach the height of poignant anguish. The rôle of the thalamus in the "feelings," the emotions, has already been pointed out, and there is no good reason for regarding the emotional pain of

melancholia as other than a disturbance of the nuclear aggregations of the thalamus and as hallucinatory in character. This is proved—one might almost say—by the existence of cases of melancholia without any other mental symptom than this emotional pain. Such cases make no reference of the pain to themselves, offer no explanations, develop no delusions. They simply suffer, sometimes horribly; they moan, perhaps cry out; sometimes rock to and fro; sometimes have outbursts of frenzy. When induced to answer questions, they prove to be entirely lucid. It is this condition which is spoken of as lucid melancholia and by the older writers as melancholia sine delirio.

However, in the ordinary case of melancholia, as just pointed out, the patient refers the symptom to himself. He himself, and not some one in the outside world, is the cause of his suffering. A sense of wickedness, of guiltiness, naturally follows, and soon the cortex, utilizing some incident in the past life, usually trivial and often wholly imaginary, develops ideas of self-accusation and, finally, the delusion of the unpardonable sin.

Further in some cases of melancholia, special sense hallucinations are added; that is, the special sense nuclear aggregations of the thalamus also become involved. As before, these hallucinations are painful, and naturally, in keeping with the exteroceptive character of the nuclear aggregations, they are referred to the outside world. They may consist of shrieks and cries, of scoldings, threats, vituperations, of tortures, burnings, horrible visions. However, they are regarded by the patient as punitive, as deserved, as only in keeping with the sins, the crimes he has committed; and thus they reinforce the self-accusations, the delusion of the unpardonable sin.

Another fact of importance must now be added, namely, that in melancholia there is a marked slowing, a marked retardation of the mental processes. Quite commonly the patient answers questions slowly and only after an interval. Sometimes this symptom is exceedingly marked, the patient sitting as though spell-bound, answering with difficulty, uttering a few poorly enunciated words or perhaps answering not at all. There is clearly a delay of transmission which is to be referred not only

to the depression of function of the cell bodies, but more especially to interference at the synapses, and this is entirely in keeping with the view that the depression of endocrine function is accompanied by a toxic action.

In the phase of mania, the resistance of the synapses is greatly diminished; there is a general release of inhibition. It would seem that as a result of the toxic hormones or other causes at work, the neurones evolve and discharge their energy with unusual ease; and that this energy flows with lessened resistance along the cell processes. The patient is expansive, aggressive, boisterous, boastful, buoyant. He talks incessantly and with great rapidity; he rapidly embraces the objects and persons in a room in the scope of his perceptions, but fastens his attention upon nothing. Illusions of objects and persons, due in part to the fragmentary and imperfect character of the perceptions and in part to abnormal associations, are a natural consequence. The associations are usually striking, unexpected; often they consist of meaningless rhymes, similarly sounding words or syllables, puns, mere assonances. There is an enormous increase

in the flow of ideas, but the latter are evanescent, fugacious, unessential; what we hear is richer in words than in ideas.

The expansion and the enormously increased association in mania is in keeping with heightened nervous outflow, the increased energy discharged by the neurones. Along with this are the motor excitement and the unusual, the bizarre, the pathological character of the associations. We can understand, perhaps, why the nervous overflow should pass along unaccustomed channels; perhaps, also, why the associations lose their intimate, elaborate, and finer qualities; why they should become coarse or relatively so. Normal acts require time, and probably in proportion to the amount of detail. In mania the discharges appear to be diffused *en masse* and probably along the larger pathways in which the least resistance is encountered. Possibly there is here an explanation of the coarseness and superficiality of the associations. Finally, it is probable that fatigue early impairs the synapses upon which the finer adjustments depend, so that as the case progresses coarse and flaring associations alone are present. Hallucinations

and delusions are noticeably absent. Impacts stream through the nuclear aggregations of the thalamus to the cortex, but the sensations transmitted are not retained, not elaborated. The transmissions stream in massive volumes to the motor exits. Only now and then and only during a temporary lull in the excitement does the patient behave as though he experienced hallucinations.

Paragraphs upon the mental disturbances and dementias which ensue upon the gross destructive action of poisons, such as lead and alcohol, and upon the destruction of the neurones by the ravages of the spirochæte of syphilis and other agents, hardly seem necessary. The action of these is obvious and the details do not here concern us. Alcohol in moderate quantities appears to act as a stimulant to the cardiovascular apparatus and possibly to other visceral groups, but as regards the neurones, retardations and modifications of function ensue that leave no doubt that alcohol acts upon the synapses and makes both transmissions and new combinations more diffi-

cult. In a general sense this is true of other poisons. As regards syphilis, the spirochæte, acting in a destructive way upon the cortex, leads to the dementia of paresis. The latter may present, as is well-known, the superadded features of depression or expansion. In either instance we have to do with the play of the spirochæte upon the thalamus, upon the cortex, or upon the thalamocortical relations. Of course, in this connection, the possibility of the direct action of toxins upon the nuclear aggregations of the thalamus must be borne in mind.

As regards the mental changes which take place in later life and in old age, these are the result of a diminution of the capacity of the neurones for the making of new combinations; as already indicated in the body of the essay. This is, however, a variable factor; some individuals lose this capacity at a comparatively early age, soon after middle life or even earlier. Others retain this capacity to a remarkable degree at very advanced periods.

Further, there is unquestionably in addition to the failure to make new combinations in advancing years, also a degenerative change which is indicated by a failure to remake old combi-

nations—*i. e.*, by a failure of memory—and further by diminutions and vagaries in the emotional responses. Here the determining factors consist, on the one hand, of the original biological vigor and resistance of the individual and, on the other, of the encroachments of disease and of time.

Unfortunately the inability to make new neurone combinations, *i. e.*, to admit new ideas, is not limited to advancing years. Prejudice, for instance, which is so harmful to the free play of the intellect, is frequently developed in early life. In its chief characteristic, it closely resembles the delusion. The delusion is featured by the inability of the person holding it to accept evidence. Prejudice is featured by an "unwillingness" to accept evidence, an unwillingness that is so great as to amount to inability. Quite commonly the attempt to break up old neurone associations—the mere thought of changing the ideas concerning a given subject—may cause pain and distress. Our thoughts and beliefs are bound up in a large measure with our feelings (see p. 135), and the more firmly established the prejudice, the greater the play of the feelings and the

greater the resistance. The result is that the individual commonly passes through life hampered by opinions and beliefs which are in large part erroneous and which have no adequate foundation.

APPENDIX

XIX

FREUDISM

The reader will have noted that in the foregoing consideration of the pathological physiology of mind, the writer has not concerned himself with the puerilities of Freudism. However, among the votaries of this peculiar cult are found a number of physicians and a still larger number of lay persons. The latter, usually without previous scientific training, have taken up the subject from idle interest, from motives of curiosity, or, more frequently, with the object of practising its teachings in the community. The term adopted by Freud and his followers, "psycho-analysis," implying as this does the "analysis of the mind," the "analysis of the soul," is high sounding. It suggests an exploration of the recondite mysteries of human existence, of human experiences and activities. No wonder that it serves as a catchpenny for the unwary and unthinking, for those who are

only too eager to adopt new views and doctrines in the belief that such an attitude places them in the forefront of intellectual progress.

Though the objects of the present volume will not permit of an extended consideration of Freudism, a brief presentation of the subject is necessary in order to place it in its proper light. In the early 80's of the nineteenth century Breuer, of Vienna, made use of hypnotism in the study of hysteria and he devised a method of treatment which he termed "catharsis." Later, in 1895, he, together with Sigmund Freud, published a volume on the subject entitled "Studien ueber Hysterie." It was claimed by them that a given symptom in hysteria immediately and permanently disappeared whenever they were successful in arousing in the patient under hypnosis the memory of the occurrence which had given rise to the symptom, if at the same time the patient could be induced to give vent verbally to the associated emotion. Subsequently Freud dispensed with hypnotism and named the procedure psycho-analysis. That patients suffering from hysteria react in the same way with or without the previous induction of hypnosis is well known. Further, that

memories evoked under hypnosis are worthless and fictitious is also a matter of common knowledge. Finally that Breuer and Freud realized the common nature of hypnosis and hysteria is evident from the fact that they speak in their book of the "hypnoid state" of their patients.

Freud's method consists in placing the patient upon her back on a couch. She is then requested to tell everything that comes into her mind, whether she thinks it important or unimportant, whether it seems relevant or senseless. She is especially requested not to suppress any thought or idea because this is intimate or shameful. This method is known as that of free association. The procedure invariably results in the unearthing, as the Freudians believe, of repressed memories of sexual occurrences, "sexual traumata," experienced in childhood.

Again, Freud believes that in dreams we have another method of access to repressed memories. According to Freud every dream has a sexual content. In the dreams suppressed sexual complexes are supposed to come to the surface, and the desire, veiled or frankly expressed, is thus

gratified. Freud has invented a "critic" or "censor" who acts as a guardian over the sleeper. The suppressed desire forms a compromise with this guardian, and it may be modified, symbolized, and the desire so modified is fulfilled.

A third method employed by the Freudians for the unearthing of repressed complexes is that of the association test. The patient is told that as soon as he hears a given word, he is to utter the first word that comes into his mind. A series of words is then read to him, and the time elapsing between the reading of the "stimulus words" and the "reaction words" is recorded by a stop watch. If it be found that the reaction time in a given instance is suddenly increased, as though there were a period of hesitation, it is suspected that a repressed complex has been aroused. It need hardly be added that this complex, according to the Freudians, is always sexual in nature.

To such sexual repressions the Freudian sect ascribes every known form of nervous and mental disorder, with the sole exception of those affections, the actual organic, infectious or toxic nature of which it is impossible to

deny. The memories of sexual traumata being unpleasant are repressed and not permitted to enter the field of consciousness, but the attempt to repress such a memory is only partially successful. Though buried, it is supposed to be still active, and it manages to reach the field of consciousness by "displacement" and "conversion." The unpleasant feeling associated with the memory leaves the latter and joins itself to some other complex which has free access to the field of consciousness, and in so doing gives birth to fears, obsessions, delusions, tics, or other symptoms. Freud does not hesitate to make of the emotions separate things, mobile somethings, capable of being detached, displaced, and producing effects which have no relation to the origin of the emotion. Again he assumes that, as in the case of the "critic" or "censor" of the dream, there is in the unconscious mind in the waking state a something which manifests itself as an effort at self-protection, so that thoughts with unpleasant emotional content are shoved into the unconscious, but there only to give rise to other troubles. That this theory is not in accord with universal experience can, I think,

be safely maintained. It is quite impossible, thus, to forget a real worry, such as a crime, a financial disaster, or the death of a beloved child. Indeed, the greater the worry, the more insistently is it present to the mind.

Further, the repressed ideas brought to the surface by free association, by dreams, or by the association test do not signify what they seem to signify, but are masked and disguised; they are merely symbols. The interpretation of the latter depends upon the imagination, the autosuggestion of the Freudian. At times the symbols indicate what they most readily suggest; at times, and apparently without reason, the opposite. There can be no doubt that the psychanalyst always finds that for which he is seeking. There is not a single object in the universe in which a sexual significance cannot be discerned, whether it be a hat, a cup, a snake, a horse, a toothpick; even the physician's stethoscope is believed to be a phallic symbol. As a matter of course, the conclusion to be formed from the investigation of a given case already exists preformed in the psychanalyst's mind, namely, that there are present in the patient repressed sexual memories. The

analyst regards this preformed conclusion as an axiomatic truth. The objection to this whole matter lies not so much in the unpleasant and repulsive character of its details as in the hopelessly illogical character of its doctrines and the unscientific character of its methods. A knowledge of nervous and mental disorders is, of course, unnecessary to the psychanalyst; a diagnosis is superfluous.

Among other things we are told that the child is in a state of auto-eroticism from which arise all of the determinations of its future soul-life. The first sexual tidal wave is reached at three or four years of age, and the dominating factor is incestuous love, the "Œdipus complex." In later life the tendencies of the individual are likewise determined by his eroticism; thus the "sublimation of erotic and criminal tendencies" gives rise to the surgeon. Economy, love of order, and obstinacy indicate anal eroticism. Luxurious water-closets also indicate anal eroticism. The love of domesticated animals, the liking for sports, are likewise the outcome of the libido (the sexual desire). The dream and the neuroses alike embrace not only the life of the child

but also that of the savage and primitive man. The epileptic attack is a retrogression into the infantile period of wish-fulfilment by means of incoördinate movements; it is an overpowering of the moral consciousness by the criminal unconsciousness; it replaces the sinful sexual act. Melancholia and mania, we are told, are the product of the repressions and displacements of the converted sexual desire, the transformed libido. Delusions of jealousy have their origin in the projection by the husband of his repressed polygamous impulses on his wife. A cause of paranoia is unmasked as an irritation of the anal erogenous zone, or it is the outcome of unrequited homosexual love. The symptoms of dementia præcox are conditioned by thoughts which, because of their unpleasant character, are repressed; the delusive ideas of the patient are merely symbols of thoughts. The patient suffers from "reminiscences of humanity" while "his history embraces all mythology." The real underlying, the fundamental, the central phantasy of dementia præcox is, of course, the incest—the Œdipus—complex. Freudism further explains migraine, every form of headache that

not organic, asthma, angioneurotic edema, hysterical, sneezing, mucous colitis, and what not. In what words shall be characterized such fantastic nonsense, such vacuous harebrained absurdities, such meaningless jargon! And such utterances are dealt with by the Freudian sect as though they were each and every one scientifically demonstrated facts, self-evident, axiomatic truths.

The psychology of insanity, the psychological interpretations of the symptoms, is one thing, psychanalysis is another. The psychology of insanity is a legitimate field of scientific inquiry. Psychanalysis, on the other hand, is a cult, a creed, the disciples of which constitute a sect. To be admitted to its brotherhood it is merely necessary that the novice should be converted to the faith, not that he should be convinced by scientific proof; for none such is possible. If the convert claims that he has found psychanalysis followed by cures, he places himself side by side with those who claim cures by means of hypnotism, divine healing, Christian Science, and like procedures.

Under the influence of mystic theories and suggestion, the less stable and weaker minds

lose their moorings. That which is old and has perhaps been acquired slowly, with difficulty and at great cost, is forgotten. Truth is rejected for no other reason than that it is old.[1] New things are accepted for no other reason than that they are new. There is an abandonment of all previous standards. The mind is unhinged and takes refuge in mysticism. The real gives place to the unreal, the beautiful to the unbeautiful, the wholesome facts of life to the morbid untruths of disease; actual experiences are belied by pathological illusions; the evidences of the senses are replaced by the phantasms of exhaustion.

The writer has many times expressed himself on this subject, and would refer the reader to his Manual on Mental Diseases or to his treatise upon Rest and Suggestion; also to the admirable exposition of the mysticism of Freudism by Knight Dunlap[2]; to the noteworthy presentation of the subject by Dr. Charles K. Mills at

[1] "A rejection of everything old because it is old is mischievous in its tendency. It is a spirit of literary licentiousness which seeks a reputation for genius and originality by thinking as no one has ever thought before, courting singularity for the sake of notoriety."—John Ludlow, Provost, University of Pennsylvania, 1834–1853.

[2] Dunlap, Mysticism, Freudianism, and Scientific Psychology, St. Louis, 1920.

the annual meeting of the American Neurological Association, in June, 1921[1]; to the Critical Examination of Psychanalysis by A. Wohlgemuth,[2] and last but not least to "Psychoanalysts Analyzed," by P. McBride.[3]

In conclusion I may be permitted to point out, first, that the Freudians ignore as unworthy of attention the evident and grossly patent fact of the biological inferiority of the neurotics and the insane as a class; secondly, that upon this already morbid soil they graft by their "technique" *i. e.*, by their suggestions, their own ideas of "repressed sexual complexes," "sexual traumata," the "libido," the "Œdipus complex," the incestuous longings, homosexuality, perversions, and bestialities. They ignore the fact that just as the body may reveal the evidences of arrest and deviation of development, so may the mind. That such arrests run parallel with arrests of the brain is shown by our studies of the brains of idiots and feeble-minded children, and when we deal with patients suffering from the neuroses and

[1] Published in the Archives of Neurology and Psychiatry of the same year.

[2] Macmillan Co., New York, 1923.

[3] William Heinemann, London, 1924.

mental affections generally, we are dealing with individuals of whom it is equally true that they are organically defective. This is the essence of what is meant by "neuropathic" and "neurotic." The neuroses reveal not only in the history of heredity but also frequently present upon the person of the patient the evidences of an imperfect or deviate development. Mentally, likewise, the neuroses present deficiencies and deviations which give to each its basic symptomatology, and which in each are innate and developmental. One could with equal reason attempt to cure a harelip or a cleft-palate by talking at it, or to cause a cervical rib or a supernumerary digit to disappear by the same means as to attempt to cure, for instance, a case of dementia præcox by psychanalysis. Does it not seem the height of absurdity to talk of such a treatment for a patient with the ear-marks of a defective development, a positive Wassermann, a toxic metabolism, defensive ferments, and other basic abnormalities, by "psychanalyzing" the patient? At most, surface symptoms alone can be played upon; the underlying basic condition can never be in the slightest degree influenced. And, as

regards the claims of cure in the slighter nervous disorders, *i. e.*, those in which there is "nothing the matter after all," Freudism stands on the same footing as Eddyism, Christian Science, and like forms of mental healing. Like the latter, it is mystic medicine.

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